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Asbestos in the Great Lakes Basin with Emphasis on Lake Superior: A Report

Great Lakes Research Advisory Board

ASBESTOS in the GREAT LAKES BASIN

with emphasis on Lake Superior

FEBRUARY 1975

A Report to The International Joint Commission from The Great Lakes Research Advisory Board

"There has been a prima facie case of a public health threat by the discharge (of Reserve Mining Co.) into the air and water... If at the end of this case I am still concerned about the public health as I am now, I will consider closing the plant immediately."

—U.S. District Court Judge Miles Lord, February, 1974.

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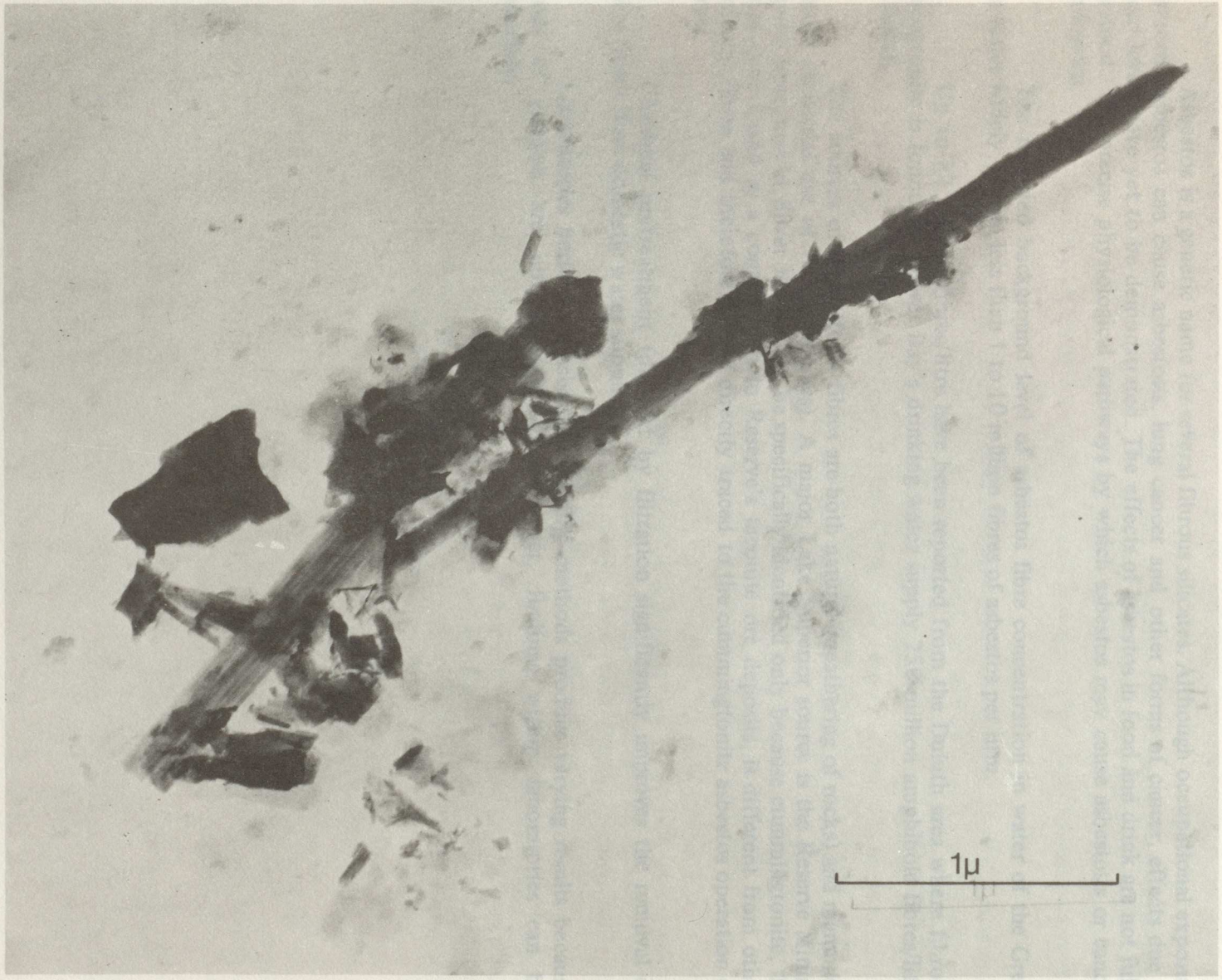
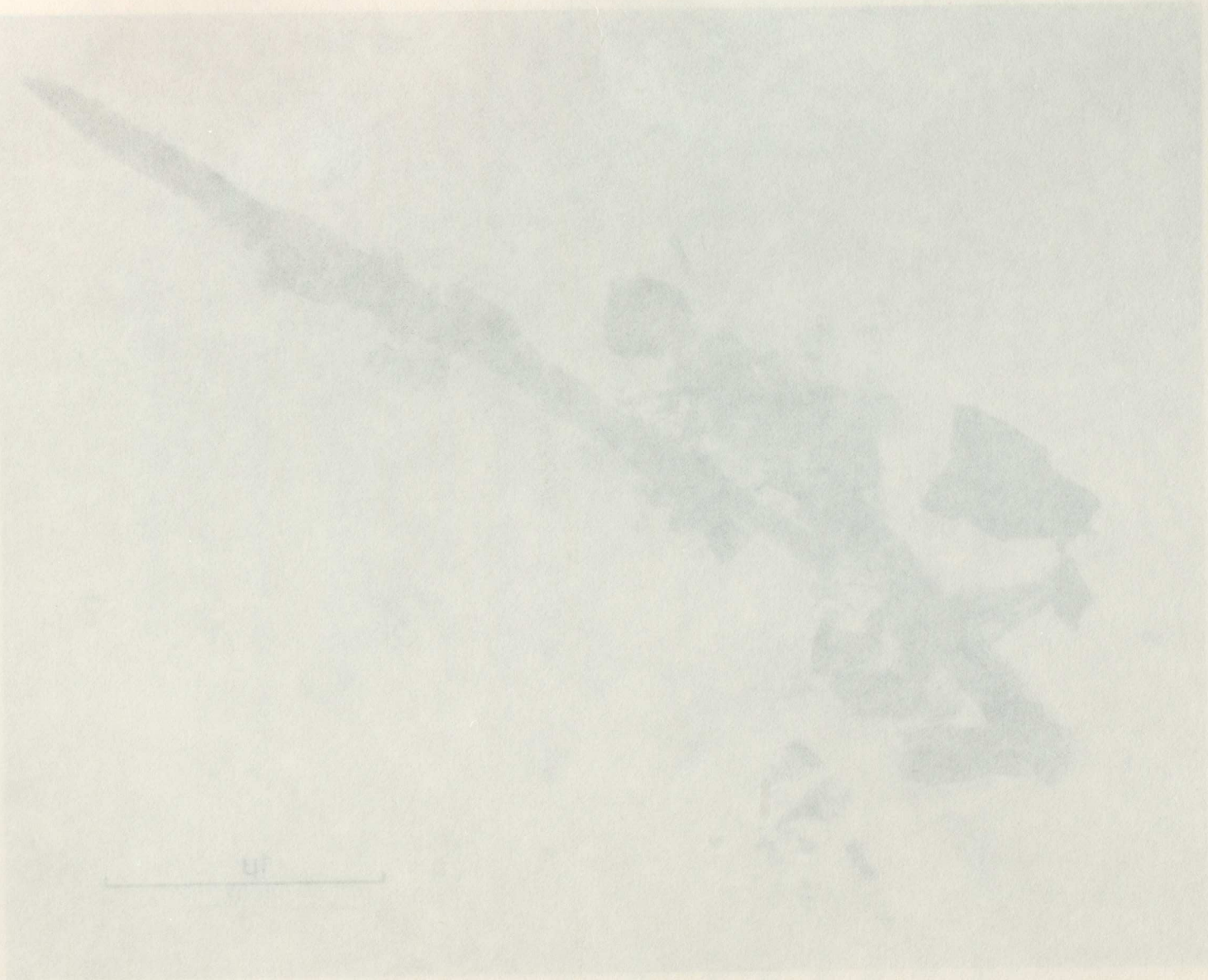


Transmission Electron Microscope Photograph of a Less than 2 μm Fraction of Taconite Tailings.

(Courtesy Canada Centre for Inland Waters)



Transmission Electron Microscope Photograph of a Less than 2 μm Fraction of Taconite Tailings.

(Courtesy Canada Centre for Inland Waters)

SUMMARY

1. Asbestos is a generic name for several fibrous silicates. Although occupational exposure to air-borne asbestos can cause asbestosis, lung cancer and other forms of cancer, effects due to ambient levels have yet to be demonstrated. The effects of asbestos in food and drink are not fully understood. The precise physiological pathways by which asbestos may cause asbestosis or cancer are unknown.

2. The reported background level of asbestos fibre concentration in water of the Great Lakes varies widely – from less than 1 to 10 million fibres of asbestos per litre.

3. Up to 87 million fibres/litre have been reported from the Duluth area where fibrous cummingtonite is found. In Beaver Bay's drinking water supply 250 million amphibole fibres/litre were found.

4. The sources of asbestiform fibres are both natural (weathering of rocks) and manmade (intensive industrial use of the substances). A major Lake Superior source is the Reserve Mining Company operation at Silver Bay. It can be specifically identified only because cummingtonite, the asbestos type found as a contaminant in Reserve's taconite ore deposits, is different from other asbestiform fibres and therefore can be directly traced to the cummingtonite asbestos operation of Reserve.

5. Chemical pretreatment followed by filtration significantly improves the removal of asbestos fibres from domestic water supplies.

6. Laboratories performing asbestos counting methods produce varying results because methods of analysis are not standardized. However, findings within laboratories can be reproducible.

SUMMARY

INTRODUCTION

REPORT PURPOSE

Because of the current controversial nature of asbestos as it relates to possible health hazards and potential transboundary pollution, the Great Lakes Research Advisory Board of the International Joint Commission on March 7, 1974, directed Regional Office staff to prepare this summary report on the status of research investigations on asbestos in the Great Lakes, particularly in Lake Superior.

Pioneering observations of the Canadian Department of National Health and Welfare and the Ontario Ministry of the Environment of asbestos in surface waters in Canada and Ontario[1,2], particularly in asbestos mining areas, provide a starting point for the summary of research investigations and state-of-the-art review which are embodied in this report. The report follows the recent shift in emphasis to western Lake Superior where disposal of taconite tailings from Reserve Mining Company operations into Silver Bay has been the subject of intense technical and legal activity. The chronology of events and the role of the Commission in its concern for boundary water pollution is pointed out. Recent actions by the U.S. courts are of particular interest in what has been termed a "classic case"[3] because their implications extend far beyond the Reserve case. Information specific to taconite mining and the Reserve case appears in the appendices of this report.

Analytical quality control problems of water sampling and laboratory identification and enumeration of asbestos fibres in water are summarized in a special chapter which also presents a comparison of analytical results from different laboratories. This chapter appears after the properties which make asbestiform fibres so difficult to analyze consistently are discussed.

Chapters detailing the health effects of asbestos and the present technology for its treatment and removal from water precede descriptions of the distribution of asbestiform fibres throughout the Great Lakes System and more specifically in Lake Superior. With this information and recognizing the current investigations *(Appendix 4)*, the Great Lakes Research Advisory Board presents its recommendations, conclusions, and its list of research needs.

PROPERTIES OF ASBESTOS

INTRODUCTION

Asbestos is a generic name used to describe several fibrous hydrated silicates, consisting of 40-60% silica in combination with oxides of iron, magnesium and other metals. Asbestos is a commercial product. The minerals differ in their chemical and physical properties, such as range of fibre diameter, flexibility, tensile strength and surface properties. They can be divided into two major groups of asbestos; the sheet silicates (chrysotile), and amphiboles (anthophyllite, cummingtonite, grunerite, crocidolite, tremolite, eckermanite). Amphiboles can be either fibrous or block-like. Asbestos or asbestiform is usually used in context to a commercial or potentially commercial deposit whereas acicular (needle-like) or fibrous are terms used more commonly in a strictly mineralogical sense. Whenever the term fibre is utilized in this report, it refers to a mineral form which is at least three times as long as it is wide.

MINERALOGY

The word amphibole is derived from the Greek word meaning ambiguous. Without careful work these minerals can be easily misidentified. In particular, variations are to be anticipated in cell parameters, electron diffraction and x-ray diffraction patterns are similar for various amphiboles, and compositions are overlapping. The characteristic mineralogical features of asbestos fibrous minerals are summarized in Table 1.

Chrysotile (white asbestos), which is used in about 90% of all products requiring asbestos, is a member of the first group. It is a magnesium silicate with the empirical composition $3MgO.SiO_2 2H_2O$. The fibres are small in diameter (200-250Å) and hollow (inner diameter 20-50Å) with apparently amorphous material on the outside and inside of the tubes.

Other forms: fibrous cummingtonite and crocidolite, tremolite, anthophyllite and eckermanite are of minor commercial importance. Estimates of asbestos reserves suggest no shortage of supply in this century.

The essential feature of the structure of all amphiboles is the presence of SiO_4 tetrahedra linked to form double chains having the composition $(SiO_4O_{11})_n$. Their structure admits great flexibility of ionic replacement, but the physical properties of all of the minerals are very similar. The minerals tend to form needle-like crystals which, when broken, produce needle-like fragments about 800-1,000Å wide. They can be divided into two groups, the ortho-amphiboles and the clino-amphiboles. The first group contains anthophyllite with the empirical formula $(Mg,Fe)_7 Si_8O_{22}(OH)_2$. The second group has two series:

- cummingtonite - grunerite series, with compositions ranging from $Fe_2Mg_5Si_8O_{22}(OH)_2$ to $Fe_7Si_8O_{22}(OH)_2$. Amosite (brown asbestos), which is of economic importance, has a variable composition averaging $Fe_5Mg_2Si_8O_{22}(OH)_2$. Crocidolite (blue asbestos) is a sodium iron silicate with the formula $Na_2Fe_5Si_8O_{22}(OH)_2$.
- tremolite-actinolite-ferroactinolite series ranging in composition from $Ca_2Mg_5(Si_8O_{22})(OH)_2$ to $Ca_2Fe_5(Si_8O_{22})(OH)_2$.

TABLE 1.

MINERALOGY OF COMMON ASBESTOS MINERALS(5)

Name	Group	Structure	Composition	Cleavage	Crystal System	Cell Lattice Dimensions	Occurrence etc.
Chrysotile	Serpentine	Sheet silicate	$Mg_3 (Si0_5) (OH)_4$ constant (Trace Ni, Cr, Al, Fe^{+2}, Fe^{+3})	perfect basal cleavage	monoclinic Cm	a=5.3 b=9.2 c=7.3 β=90°	low grade metamorphism ultrabasic rocks
Anthophyllite	Amphibole	Double chain	$(Mg, Fe)_{5-6}$ $Al_{1-2}(Si_6 (Si, Al)_2 0_{22})$ $(OH, F)_2$	(210) perfect	orthorhombic Pn ma	a=18.5 b=17.7 c=5.3	metamorphic rocks
Cummingtonite Grunerite (Amosite)	Amphibole	Double chain	$(Mg_4 Fe_3) (Si_8 0_{22}) (OH)_2$ to $Fe_7 Si_8 0_{22} (OH)_2$ $(Mg_2 Fe_5) (Si_8 0_{22}) (OH)_2$ Mn common substitute	(110) good (110) : $(1\bar{1}0)$ =55°	monoclinic C2/m	a=9.6 b=18.3 c=5.3 β=102°	metamorphosed iron formations (retrograde and amphibolites)
Crocidolite (Cape Blue)	Amphibole	Double chain	$Na_2 Fe_3{}^{+2} Fe_2{}^{+3} (Si_8 0_{22})$ $(OH, F)_2$ Mg substitutes for Fe^{+2} Ca for Na	(110) good (110) : $(1\bar{1}0)$ =56°	monoclinic C2/m	a=9.8 b=18.0 c=5.3 β=103°	in iron formation as metamorphic mineral
Actinolite Tremolite	Amphibole	Double chain	$Ca_2 (Mg, Fe^{+2})_5 (Si_8 0_{22})$ $(OH, F)_2$ $Ca_2 Mg_5 (Si_8 0_{22}) (OH, F)_2$ Al substitutes often; see hornblende	(110 good (110) : $(1\bar{1}0)$ =56°	monoclinic C2/m	a=9.9 b=18.1 c=5.3 β=105°	actinolite in Fe formations tremolite in metamorphosed calcareous rocks

The main sources of asbestos fibres in the environment are from the mining and milling of asbestos materials, milling and beneficiation of iron, copper, nickel and zinc ores that contain fibres, plants and factories manufacturing products containing asbestos, and the "waste" from its general usage in modern society. When the minerals containing asbestos fibres are crushed, they have the property of splitting lengthwise into fibres of varying strength and flexibility. A considerable portion of the fibres are microscopic in size and enter the atmosphere as dust from sources such as insulation materials and brake linings. Consequently, it is common to find asbestos fibres in high concentrations in the air and water surrounding cities. Mining and milling operations create large amounts of airborne particles including asbestos. Dust prevention in plants and factories has reduced, but not eliminated completely, air particles in the immediate surrounding area.

There are about 3,000 commercial uses of asbestos, in particular, asbestos cement building materials and water distribution system pipes, floor tile, paper products, paint, caulking, fireproofing, packing, brake lining, clutch facing, electrical insulation, vinyl sheet backing, covering for jet engines, filters, and heat resistant plastics. The U.S.A. is the world's largest consumer of asbestos, consuming 3.5×10^6 short tons in 1968 and about 20% of all world production. By the year 2,000 the U.S.A. is expected to double its present consumption. Canada is the largest producer of asbestos, producing about 46% of the world's production principally in Quebec and exporting about 90%, mostly to the U.S.A.[4].

CHEMISTRY

The chemical composition of commercially available chrysotile from various locations deviates little from the ideal composition $Mg_3Si_2O_5(OH)_4$. The impurities, in particular iron, aluminium, calcium, chromium, etc., may be part of the crystal structure or may be introduced by associated minerals. Silicon may be replaced by aluminium, and magnesium by aluminium, ferrous and ferric iron.

The chemical composition of the asbestiform amphiboles is more complex than that of chrysotile (Table 1). The amphibole structure admits great flexibility of ionic replacement, and the minerals of the group exhibit a wide range of chemical composition. In addition to the replacement (Mg,Fe), important substitutions occur in the amphiboles; for example, the substitution of silicon by aluminium, calcium by sodium, and (Mg, Fe^{+3}) by aluminium.

The chemistry of standard reference asbestos samples has been described in a number of review papers[5]. Analyses have been determined by electron microscopic fluorescence analysis and microprobe analysis and are listed in Table 2. At present, there are no published data on the changes in chemical composition of individual asbestos fibres after immersion in water.

MORPHOLOGY

Chrysotile

Chrysotile fibres and fibrils are distinctive in their appearance and their morphology is usually utilized for their identification by electron microscopy. Chrysotile fibres usually are curved and occur in open bundles splitting into fibres and fibrils of 200-400Å in diameter (1 Ångstrom = 10^{-10} meter). Chrysotile fibres readily divide into numerous flexible fibrils; a chrysotile fibre of 1 μm diameter can yield 1,000 fibrils of the same length, for example, in lung liquids[6,7]. Consequently, no reliable geometric size measurements can be made with chrysotile fibres. The fibrils have various diameters but the average outer diameter is of the order of 250Å and the inner diameter about 50Å.

TABLE 2

CHEMICAL COMPOSITION RANGE OF INDIVIDUAL ASBESTOS MINERALS BY MICROPROBE ANALYSIS[7]

Oxide	Chrysotile	Amosite	Crocidolite	Anthophyllite	Tremolite	Actinolite
SiO_2	38.0-44.0	49.0-53.0	49.0-53.0	56.0-58.0	51.0-60.0	51.0-56.0
UICC	[38.6]	[50.3]	[49.1]	[58.2]		
MgO	40.0-42.0	1.0-7.0	0.0-0.3	28.0-34.0	15.0-26.0	15.0-20.0
UICC	[32]	[11]	[3.6]	[24]		
Fe oxides	0.0-4.0	34.0-44.0	30.0-40.0	3.0-12.0	0.0-15.0	5.0-18.0
UICC	[2.6]	[28]	[27]	[4.4]		
CaO	0.0-1.0	0.0	0.3-2.7	0.0	10.0-13.0	10.0-12.0
UICC	[0.1]	[0.2]	[0.7]	[0.01-0.1]		
Na_2O	0.0-TR	0.0	4.0-8.5	0.0	0.0-TR	0.5-1.5
UICC	[0.001-0.1]	[0.006-0.06]	[7.0]	[0.007-0.07]		

UICC (International Union Against Cancer): STANDARD REFERENCE SAMPLES

Although typical electron micrographs of chrysotile show smooth cylindrical fibres, other forms are observed occasionally; for example, tube-in-tube form and cone-in-cone form. Quite frequently there is a median stripe of greater electron density on the plate of the fluorescent screen suggesting that the centre of the fibre is more transparent to electrons than are the sides of the fibre. The simplest interpretation of this phenomenon is that the fibres have a tubular morphology. Most of the fibres have a hollow cylindrical form. The tubes are not simple cylindrical cones, but consist of deformed layers arched toward one another, approximating a hollow cylinder. Some fibres, however, are not hollow but solid, showing an unusual growth pattern. Filling the cylinder with foreign material also may result in a solid appearance. The density of Arizona and African chrysotile is compatible with tubular structure, but Canadian chrysotile with a high density has at least 50 percent filled tubes.

It should be noted that fibre width generalities may be of little real use since the same mineral from a different locality or crushed differently can have smaller fibre widths.

Amphiboles

The most striking difference between chrysotile and amphibole fibres is in their shape: the amphiboles are usually straight and show good cleavage. Amphibole fibres do not split or change shape in lung fluids and are thus observed in the same state as when inhaled.

Although widths of fibres vary according to source and to milling processes, Timbrell *et al*[8], have reported that the fibre width of anthophyllite invariably exceeds the average width for amosite, which again exceeds the average width for crocidolite. The minimal fibre diameters quoted are as follows: 2500Å – anthophyllite; 1500Å – amosite; and 600Å – crocidolite.

FIBRE LENGTHS

Since asbestos fibres up to 200 μm long have been detected in lungs, fibre length distributions have been determined for the reference samples up to this approximate limit. It was shown in laboratory experiments that the observed distributions depend to some extent on the method used to disperse the fibres for measurement. These results are summarized in Table 3[9,10].

SURFACE AREA

The specific areas of the asbestos fibres are important for the study of kinetics of dissolution of asbestos fibres in water. The surface areas of the reference sample were measured using both nitrogen adsorption and permeability methods[11,12]. Results are shown in Table 4. The values obtained by the nitrogen adsorption method include all the internal surface of pores, cracks, etc., while the permeability method measures only the external surface. The rating of the sample by the two methods is different, reflecting the different structure of the various types of fibre.

SURFACE CHARGE

The isoelectric point of chrysotile is at a pH of 11.8. At lower pH values the surface charge is positive; above the isoelectric point the charge becomes negative. Most dispersed materials have a negative surface charge in aqueous systems. Since chrysotile has a positive charge, it attracts or is attracted to most dispersed materials.

The isoelectric point of cummingtonite amphibole is 5.2 to 6.0. Therefore, in most waters the mineral has a negative surface charge represented by a zeta potential of -20 to -40 mv.

TABLE 3

LENGTH DISTRIBUTION OF REFERENCE SAMPLES[9,10]

Asbestos Type	% by number in given size range (μm)								
	.2-.5	.5-1	1-2	2-5	5-10	10-25	25-50	50-100	100-200
Amosite	23.00	31.10	25.50	14.70	4.40	1.08	0.16	0.03	0.02
Anthophyllite	21.80	32.70	22.50	18.20	3.50	1.15	0.14	0.00	0.00
Crocidolite	28.40	35.80	22.50	10.30	2.33	0.60	0.07	0.000	0.01
Chrysotile A (Rhodesian)	20.70	34.90	23.10	15.20	2.83	2.49	0.62	0.15	0.00
Chrysotile B (Canadian)	30.60	33.40	19.80	13.20	1.76	0.93	0.24	0.07	0.00

TABLE 4[11,12]

SPECIFIC SURFACE AND PERMEABILITY OF ASBESTOS

Asbestos Type	Specific Surface (m^2/g)	
	Nitrogen Adsorption	Permeability
Amosite	5.7±0.3	3.3
Anthophyllite	11.8±1.0	2.7
Crocidolite	8.3±0.5	3.1
Rhodesian Chrysotile	21.3±1.5	6.8
Canadian Chrysotile	26.8±0.7	4.9

REACTION OF ASBESTOS FIBRES WITH WATER

Holt and Clarck and Reimschussel[13] studied prolonged extraction of chrysotile with water. Holt extracted chrysotile with boiling water and found that the solution contained both magnesium and soluble silicic acid. He postulated that the chrysotile decomposed by dissolution of magnesium leaving a residue of colloidal silica that hydrolyzed to orthosilicic acid.

Reimschussel investigated the chrysotile decomposition by water in a Soxhlet extraction. The concentration of magnesium in the extract was relatively high during the first 3-4 hours of Soxhlet extraction and then began to decrease. The decrease in magnesium concentration was accompanied by the formation of a precipitate of amorphous magnesium silicate.

Cotterell and Holt[14] investigated the extraction of silica, calcium, magnesium and iron from two crocidolite samples from the Kvegas field of North West Cape (NWC) and from Transvaal (Tvl). Samples of the two crocidolites (500 mg) in fibrous form were extracted with water or 0.1 N hydrochloric acid (100 ml) for 5 days at 20°C. After filtration the concentration of the metal ions and silica were determined. The results are given in Table 5.

Both crocidolites were attacked by water as well as by 0.1N hydrochloric acid; and NWC crocidolite was dissolved more than Tvl. Silica and magnesium were extracted by water and acid; however, iron was found in solution only after acid extraction. Calcium was found in NWC solution, but was below detectable levels in Tvl solution.

TABLE 5
RESULTS OF SOLUTION STUDIES OF ASBESTOS IN HC1 AND WATER[14]

Crocidolite Type	Solute	pH		Solute, mg/100ml.				
		init.	final	Si	Ca	Mg	Fe^{+2}	Fe^{+3}
NWC	H_2O	5.2	7.9	0.68	1.0	0.4	0.1	0.1
NWC	0.1N HC1	1.2	1.2	0.90	1.0	1.5	3.3	1.5
Tv1	H_2O	5.2	7.8	0.21	0.1	0.4	0.1	0.1
Tv1	0.1N HC1	1.2	1.2	0.50	0.1	0.7	0.6	1.2

ENUMERATION AND IDENTIFICATION OF ASBESTOS

ANALYTICAL INSTRUMENTATION

Six tools are available to the analyst for the identification of asbestos fibres:

1. Infrared Spectroscopy
2. Differential Thermal Analysis
3. X-Ray Diffraction
4. Transmission Electron Microscopy
5. Selected Area Electron Diffraction
6. Electron Microprobe Analysis

The first three techniques are suitable for the characterization of large bulk samples of asbestos minerals, the last three for individual fibres. The last three, taken together, can provide unique fibre identification by morphological, structural, and chemical analysis.

Of prime interest is the identification of individual fibres in air and water samples at trace concentrations. Therefore, this report considers only TEM, SAED, and EMA in any detail. All three may be performed consecutively on the same sample in the same instrument.

Infrared Spectroscopy And Differential Thermal Analysis

Although infrared spectroscopy has been used to identify specific amphibole minerals, it measures molecular properties which sometimes are difficult to interpret. Differential thermal analysis usually is considered inappropriate because it requires highly sophisticated techniques for preparation of homogeneous, representative samples.

X-Ray Diffraction

When x-rays impinge upon a crystalline structure, they are diffracted. The resulting x-ray diffraction pattern can be translated into the characteristic dimensions and angles of the unit cell. If the composition is relatively constant, the technique can be successfully applied for fibre identification. This requires samples without significant lattice distortion. The resulting diffraction patterns can be measured, indexed, and by computer techniques, reduced to cell parameter values.

Transmission Electron Microscopy (TEM)

Figure 1 illustrates the optics of TEM. Electrons from a heated tungsten filament source are accelerated by a 40-100 kv potential. The resulting electron beam is focused onto the specimen on a grid (object) and, through a series of additional magnetic lenses and apertures, the image is displayed on a fluorescent screen or a photographic device.

The pressure is maintained below about 10^{-5} torr (one torr equals one millimetre of mercury). The TEM has been designed to permit rapid sample insertion and return to operating pressure. The apertures are adjustable, the specimen viewed can be limited by the size of the intermediate aperture.

Asbestos fibres are visible on the screen. Mineral fibres and fibrils are often distinctive enough for unique identification.

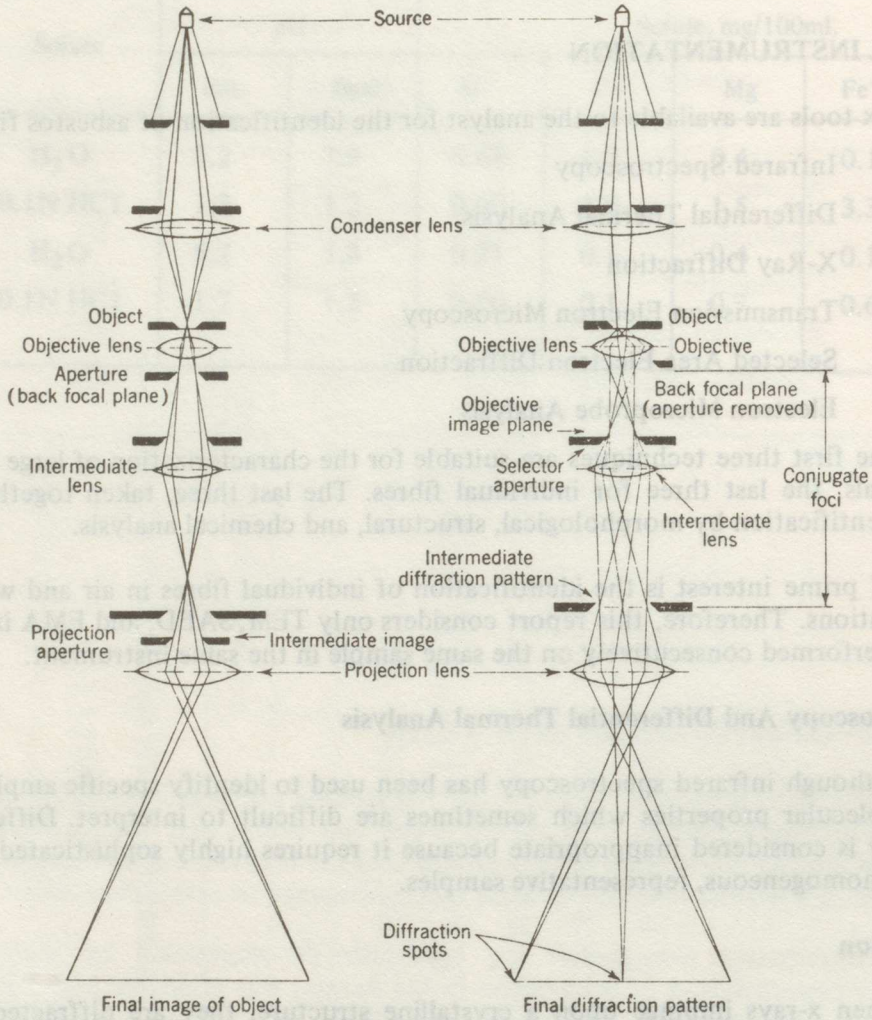


FIGURE 1: THE OPTICS OF TRANSMISSION ELECTRON MICROSCOPY

Arrangement of lenses and diaphragms in a modern high-power electron microscope. (a) Operating as three-stage electron microscope. (b) Operating to produce a selected-area diffraction pattern. (After R.D. Heidenreich, "Fundamentals of Transmission Electron Microscopy," Interscience, New York, 1964.)

*Figure and text from C.S. Barrett and T.B. Massalski, *Structure of Metals*, 3rd Edition, McGraw Hill Book Company, Toronto 1966. p. 431.

The fibres detected may have clay, diatoms, and other small particles associated with them. These and the presence of other fibrous materials may interfere with identification.

Selected Area Electron Diffraction (SAED)

By simple removal of the aperture at the back focal plane, and by limiting the viewing area to a given fibre, the electron diffraction pattern of the fibre can be produced.

Through the use of SAED, individual fibres of chrysotile can be distinguished from amosite, anthophyllite, and crocidolite. The diffraction patterns of the last three asbestiform fibres closely resemble each other, but they can be distinguished by the difference in the intensity of the points within the layer lines. Chrysotile is crystallographically different enough from the amphiboles to show gross differences, but differences from one fibre to another may be attributed to orientation. Many fibres due to size, orientation, or interference of other particles, will not give an identifiable diffraction pattern. This leads to large systematic error (low counts) when a positive SAED is required for fibre identification.

Electron Microprobe Analysis (EMA)

With EMA, a focused electron beam is moved over the surface of the specimen, exciting characteristic x-radiation. Analysis of these x-rays provides information about the chemical composition of the area under study. The resolution is a few cubic micrometres of specimen.

As with TEM and SAED, EMA is a relatively nondestructive technique. Chrysotile fibres are destroyed by an electron beam; this property is often used as a diagnostic. Amphibole fibres are less damaged.

A single fibre may be analyzed by EMA. Since all amphiboles contain silicon, magnesium, and iron, the empirical ratio of these three elements can be determined for the fibre and the resulting value plotted on a triangular three-component Gibbs diagram. Different areas on the diagram, corresponding to different ratios of the elements, correspond to the different amphibole fibres. Thus an individual fibre may be uniquely identified.

ANALYTICAL PROCEDURE

Sample Collection

Water samples are collected in new polyethylene bottles which have been properly rinsed with the sample water prior to collection. About one litre is sufficient. No special handling precautions are taken and no preservatives are added.

Filtration

Where filtration techniques are used, a 0.2 - 1.0 litre sample is filtered through a filter with 0.1 - 0.5 μm pore size. The time between sample collection and filtration is considered critical by some laboratories. Samples should be stored in closed containers prior to transfer of the non-filterable solids in the sample to the support grid of the TEM.

Grid Transfer

Several alternative procedures may be followed to effect transfer of the solids to the grid. Some utilize ashing, resuspension, and/or centrifugation as intermediate steps. One procedure also obviates filtration. These are discussed below.

Analysis

Fibre Number

A field is defined as a single opening in a TEM grid; the total number of fields is generally 200-500. A certain number of fields are viewed and the number of fibres enumerated (typically 10 fields or up to 100 fibres). The average number of fibres per field is determined. Thus, the number of fibres per volume of sample filtered is:

$$\frac{\#\text{ fibres}}{\text{volume filtered}} = \left(\frac{\text{average }\#\text{ fibres}}{\text{field}}\right) \cdot \left(\frac{\text{filter area}}{\text{field area}}\right) \cdot \left(\frac{\text{field area}}{\text{correction factor}}\right)$$

The filter area is the total area over which the particulates were deposited. The field area is also directly measurable. The field area correction factor compensates for the area of the grid bars which obscure some of the viewing area; this factor may not be routinely included.

The minimum detectable number of fibres per unit volume varies with the volume of sample processed, the number of fields counted, and the number of replicates analyzed. The limit of detection is approximately 10^5 to 10^6 fibres/litre.

Fibre Dimensions

The viewing screen is inscribed with a calibrated scale or circles of known diameter. The magnification of the instrument is known, and the dimensions of the fibres are hence easily measured. The minimum fibre diameter measurable is about 0.04 μm. The lengths and widths of all fibres in a specified number of fields are measured; from these measurements a size distribution is determined.

Fibre Volume

The volume of a fibre is calculated by multiplying its length by the width squared; this assumes a square fibre cross section. Many amphibole fibres are lath-shaped and will tend to lie on their flat side. Hence, the estimate of the volume of the fibres present will tend to be high. This small bias cannot be measured, but may be partially compensated for if some of the fibres stand on edge.

Fibre Mass

The mass of a fibre is calculated by multiplying its volume by 3.40, the average density for amphibole fibres. The total mass of fibres present per volume of sample filtered is calculated in a manner similar to that for total number of fibres.

Most of the above calculations are routinely handled by a computer.

SOURCES OF VARIATION IN ANALYTICAL RESULTS

Filters

Two types of filters are utilized. Millipore and Sartorius filters are prepared by gelification of concentrated colloidal solutions of polymers. Nuclepore filters are prepared by a nuclear irradiation-and-etching process of a thin polycarbonate film. Both filter types possess advantages and limitations. Their different characteristics may introduce bias into analytical results.

Millipore and Sartorius filters possess sufficient flow capacity to be satisfactory for routine work; Nuclepore filters are used for filtration of small volumes of water, so clogging is not a factor.

Sonification (about 30,000 Hz) may be employed to resuspend the deposit from the filter. Nuclepore filters do not disintegrate, although some breakage is observed. Sartorius filters crack and disintegrate into clusters and clumps, rendering further analysis impossible. Millipore filters are intermediate.

The amount of particulates retained on the filter depends not only on the filter properties, but also on the pore size. For example, Millipore filters will hold fibres in their pores so that many fibres are lost. Filters with nominal pore size of 0.1 - 0.45 μm are utilized.

Grid Transfer

At least six different procedures are utilized to achieve placement of the particulates onto the grid of a TEM. Their comparability has not been demonstrated.

1. A piece (about 1cm x 2cm) of Nuclepore filter is cut out and mounted onto a glass microscope slide, which is then heavily coated with Si0 in a vacuum evaporator. A 3mm-diameter disc is cut out of the coated filter and mounted, SiO side down, on a 200-mesh nickel grid. The grid is placed on a piece of polyurethane in a petri dish containing chloroform almost level with the top of the polyurethane. The Nuclepore filter is dissolved via capillary action of the chloroform through the SiO. Particulates remain, deposited on the SiO substrate on the nickel grid.

2. A Millipore filter with sample is ashed at low temperature in a microwave oven. The residue is ultrasonically redispersed in a small volume of water. An aliquot or precisely measured fraction of the sample is diluted into an aqueous detergent solution contained in a specially designed centrifuge tube with a flat, removable bottom on which a glass cover slip is placed. The sample is spun and the particulates are deposited onto the slip. The slip is removed, dried, and coated with carbon in a vacuum evaporator. The coated slip is scored, dividing the layer into segments about 3mm square. The layer is floated off the slip onto the surface of water in a petri dish. A carbon square is picked up onto a 200-mesh copper grid.

3. A 2-3mm square portion of a Millipore (or Nuclepore) filter is placed face down on a carbon-coated grid. The filter is dissolved with acetone in a Soxhlet extractor or a Jaffee dish.

4. The water sample is directly centrifuged (about 30,000 g), dried, and ashed at elevated temperature. The residue is ultrasonically resuspended in a small volume of water; an aliquot (1-5 μl) is placed with a pipette onto a carbon-coated copper grid and dried. The procedure has also been employed without the ashing step.

5. The filter is placed into a small vial, a volume of water added, and the particles resuspended with sonification. An aliquot (1 μl) is placed onto a carbon-coated copper grid and dried.

6. The water sample is directly centrifuged (about 3,000 rpm) with the particulates being deposited onto a carbon, collodion, or Formvar coated grid placed at the bottom of a special centrifuge tube.

Options 4 and 5 involve the transfer of a microlitre-sized aliquot onto the middle of the grid and only the area to be scanned. Placement is critical. The distribution of fibres is non-uniform. If the drop is placed onto the top of the grid, upon drying, the greatest number of fibres is found at the edge of the area covered by the drop; the central grid squares are essentially empty. If the grid is inverted prior to drying, the reverse is observed.

Options 2,4 and 5 utilize sonification for redispersion and homogenization. The effect of sonification is not defined, but it is possible that particulates may not be completely released (membrane filters may possess an attractive electrical charge) and resuspended, fibre clusters may be split, and fibres and fibrils may be broken. The possible occurrence of these phenomena needs to be investigated. Since undefined and possibly variable processes are occurring, a procedure relying on sonification should be avoided.

Options 2 and 4 subject the sample to ashing. Splitting, agglomeration, composition changes, and losses during ashing occur, and are variable, depending upon the exact experimental conditions chosen. Therefore, ashing should be avoided.

The preferred procedure for grid transfer would appear to be Options 1, 3 and 6. Options 1 and 3 require a homogeneous distribution of fibres on the filter and assume no loss of fibres during dissolution of the filter. The risk of contamination and of the loss of sample for Option 3 is reported to be minimal. Option 6 may be inadequate; the centrifugation rate is limited by the tendency of the supporting film on the grid to rupture, and the maximum rate may be too low.

Other Sources for Difference

A number of different procedures are capable of providing data, but none has been shown to yield correct data. No one procedure has been demonstrated to be accurate; that is, that the number and the nature of the asbestos fibres and clusters remain unchanged during collection, handling, storage, preparation, and analysis. Similarly, no one procedure has been shown to yield erroneous data, although some might be more suspect than others.

Besides the potential bias and loss of precision which might be introduced by the choice of filter and the grid transfer procedure, all steps of the analytical procedure, especially where alternatives are available, may be considered suspect. Several of these are listed below.

1. Non-homogeneous sampling initially or non-homogeneous sub-sampling at various stages of analysis
2. Sample collection procedure: pump and bottle
3. Chemical effects of the sample collection and storage container: polyethylene
4. Physical effects of the sample collection and storage container: sample loss via adsorption
5. Effect of unusual storage conditions; e.g. heat
6. Filter storage and preparation prior to use
7. Filtration technique; e.g. application of vacuum
8. Effect of sequential or re-filtration to remove debris
9. Storage of filter subsequent to filtration and prior to further processing
10. Grid storage and preparation prior to use
11. Storage of grid subsequent to sample transfer and prior to analysis
12. Effect of time
13. Enumeration procedures: number and location of fields reviewed
14. Interpretation of observations
15. Human fatigue and errors

16. Blank correction
17. Differences introduced with photographic versus a visual count
18. Clumping of particles
19. Failure to obtain a diagnostic SAED pattern
20. Contamination, particularly with chrysotile, during sample preparation
21. Observation of fibres by other material
22. Creation of more fibres by sonification
23. Inability to count very small fibres
24. Loss of fibres during grid preparation

It should go without saying that the laboratory facilities should be and remain clean; that proper care should be routinely exercised in preparing, handling, and aliquoting samples and reagents; that proper care should be exercised in preparing blanks; and that the technician or scientist should know and understand the operation of his instrumentation and be able to recognize changes in operating parameters and conditions.

INTERLABORATORY COMPARISON STUDIES

Three interlaboratory comparison studies which provide a reasonable evaluation of different analytical procedures have been reported.

Duluth Asbestos Study

The first comparison study involved two laboratories performing analyses for the U.S. Environmental Protection Agency (EPA) Duluth Asbestos Study. Laboratory A employed a sample preparation and handling procedure similar to Option 3 described under "Grid Transfer"; Laboratory B followed a procedure similar to Option 1. Water samples were collected and filtered by EPA. The filters were split, submitted and coded for analysis. The resulting fibre count data is summarized in Table 6. After deletion of those results for which "zero" *(sic)* fibres per litre were reported, the ratio of counts of Laboratory A to Laboratory B is 1.98 ± 1.51, indicating a statistically significant difference (0.95 probability) from the expected value of unity. The 1.98 indicates bias; the 1.51 is a measure of the reproducibility.

Lake Superior Asbestos Study

The second comparison study involved three laboratories performing analyses for EPA's Lake Superior Asbestos Study. Laboratory C employed a sample preparation and handling procedure similar to Option 3; Laboratory D, Option 3; and Laboratory E, Option 2. The intercomparison samples were prepared by suspending tailings obtained from Reserve Mining Company operations. After stabilization, serial dilutions were made to obtain the appropriate concentration range. The dilutions were filtered through a 0.1 μm (pore size) Millipore filter which was then quartered and distributed for analysis. This experimental design normalized variations in the intercomparison samples, and provided for checks on uneven particulate distribution onto the filter during filtration, bias between labs, and precision within a lab. The resulting fibre count data are summarized in Table 7. All values are at least an order of magnitude removed from the detection limit; the standard deviation of each is about ±50%.

These results indicate a reasonably good capability for within-laboratory reproducibility of data. However, a large, reasonably constant between-laboratory bias exists, the source of which is undefined. The low results for Laboratory C may be due in part to debris obscuring fibres.

TABLE 6

LABORATORY INTERCOMPARISON FOR DULUTH ASBESTOS STUDY

SAMPLE NO. / LAB NO.	No. FIBRES/LITRE ($X10^6$)	
	A	B
1	4.4	2.0
2	5.3	3.0
3	2.8	5.0
4	6.1	2.0
5	2.3	1.0
6	1.5	1.0
7	2.5	2.0
8	0.7	1.0
9	3.9	0.7
10	0.7	1.0
11	0	0
12	0	0
13	0.4	0.7
14	1.1	0.3
15	0.4	0.3
16	1.0	0.1
17	0	0
18	2.0	0.3
19	0	0
20	8.3	0.8
21	0.5	0.3
22	6.0	0.2
23	0.3	0
24	0.4	0
25	0.2	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

N.B. The results reported as "zero" are erroneous. These results should more correctly be reported as "less than the detection limit," which is unspecified.

TABLE 7

LABORATORY INTERCOMPARISON FOR LAKE SUPERIOR ASBESTOS STUDY

LAB. NO. / SAMPLE NO.	NO. FIBRES/LITRE ($X10^6$)		
	C	D	E
101	0.79	43.	29.
102	1.1	34.	18.
103	4.0	48.	9.
104	1.7	32.	25.
105	2.1	36.	8.
AVERAGE	1.94	38.6	17.8

Additional replicates of these same solutions, plus others collected as part of the Lake Superior Asbestos Study, have been subsequently coded and submitted to the three laboratories. The earlier observed bias constant between Laboratory C and Laboratory E has disappeared in that recent data are almost identical. This means that new and old data cannot be compared. Results from Laboratory D are scattered, indicating a lack of within-laboratory reproducibility.

Fibre mass per unit volume of sample was also determined by the three laboratories for the five samples. A similar bias between the laboratories and similar within-laboratory reproducibility were obtained.

Data are also being collected for each sample from each laboratory on the fibre size distribution. These data are incomplete.

The constant bias between the laboratories presents a problem for the Lake Superior Asbestos Study. This study is designed to determine the source of amphibole fibres in Lake Superior and to trace their distribution; therefore, only relative values are required. Through use of a proportionality constant, the data can be made internally consistent.

Litigation Study

In conjunction with the U.S.-Reserve Mining litigation, the court ordered and designed an intercomparison study. Fibre counts were reported for a series of samples by eight participating laboratories. The results tend to confirm the between-lab bias and the tendency toward occasional within-lab non-reproducibility.

CONCLUSIONS

Present analytical endeavours have responded to the immediate need for data, and have used the best analytical capability available. Nevertheless, time, personnel, and monetary constraints have limited any properly designed methods development and evaluation program.

Three conclusions may be reached:

1. The superiority of any one analytical procedure has not been demonstrated.
2. Acceptable within-laboratory precision can be achieved.
3. The achievement and maintenance of accuracy and precision through a properly designed and executed quality control program will be demanding, time-consuming, and expensive.

RECOMMENDATIONS

Methods evaluation studies should be instituted in order to establish an accurate and precise procedure in which the variables are known and understood and an adequate quality control program should be designed and evaluated so that the validity of analytical results can be ensured.

HEALTH EFFECTS

MEDICAL RESEARCH

Tiny asbestos fibres in the atmosphere are the causative agent of the disease asbestosis, a scarring of the lungs by increased fibrous tissue growth, which is an occupational hazard in the asbestos industry[15, 16]. The widespread use of asbestos materials had led to increasing concern over potential hazards to the general public[17], especially since exposure to asbestos causes malignant tumors of the pleural epithelium and abdominal cavity lining. Such exposure is normally considered to occur by way of inhalation of asbestos fibres.

A major problem in asbestos medical research is interpreting results when there is an extremely long latency period, generally 20-40 years, between initial exposure and resultant diseases.

Most research has involved chrysotile, amosite, crocidolite, and anthophyllite. Researchers express apparent conflicting opinion regarding the relative carcinogenicity of various types, but the majority agree that in general asbestos is carcinogenic.

The amount of fibres required to cause adverse reactions in living organisms has not been precisely determined. The effect of smoking is unclear. The large surface area and specific surface reaction of the fibres are suspected to have some effect on cells.

The most popular theory of asbestos carcinogenesis has been based on the size and shape of fibres. The physical dimensions are referenced frequently by researchers. Generally the health hazard from exposure to asbestos increases the more the material is separated and the fibres shortened.

A combination of factors including the basic mineral chemistry, size and shape of fibres, organic surface contaminants, and length of time of presence of fibres in the body increases the health hazards. Fibres with a favourable size, shape and surface charge may penetrate mesothelial tissue and pierce cells.

SUMMARY OF PUBLIC HEALTH HAZARDS

Inhaled Asbestos[18]

1. Hazards from Occupational Exposure
   a. Asbestosis – This disease will appear after 10 to 40 years of occupational exposure with the main symptoms of extensive fibrosis of the lungs and pronounced shortness of breath.
   b. Pleural calcification – This disease involves the deposition of insoluble calcium salts in the lining of the lung. It has about a 20-year latency period and is common among asbestos workers, but appears to vary in frequency in different occupationally exposed groups.

c. Lung cancer – The association between occupational exposure and excess incidence of bronchogenic cancer has been confirmed and is considered as the single most common complication of asbestos. Smoking compounds the risk of lung cancer in asbestos workers.

d. Mesothelioma of the pleura and peritoneum (linings of the chest and abdominal cavities) – This disease, with a latency period of 20-40 years, was considered until recently extremely rare.

e. Other cancers – A quantitative correlation between asbestos exposure and cancer of other sites has not been clearly established.

2. Hazards from Non-Occupational Exposure

Asbestos (or ferruginous) bodies (coated masses of asbestos fibres) and fibres have been found in the lungs of people who have had no occupational exposure to asbestos. Asbestos fibres have been demonstrated in ambient air. Pleural calcification, lung cancer and especially mesothelioma have been linked with situations where persons have lived near asbestos mines, factories producing asbestos goods or in homes of asbestos workers. A National Academy of Sciences Study suggests that a dose-responsive curve exists and "there are levels of asbestos exposure that will not be associated with any detectable risk. What those levels are is not known, but there is no evidence that persons in the general population – without occupational, household, or neighborhood exposures – have any risk of neoplasm, even though there may be ferruginous bodies or fibres in their lungs."(19)

3. Significance of Delayed Appearance of Asbestos-Induced Cancer

Even short-term exposures may cause mesothelioma, or cancer. Judge Miles Lord of the U.S. District Court of Minneapolis, in his supplemental memorandum to the U.S. Court of Appeals Eighth Circuit cited findings of Dr. Irving J. Selikoff of the Mount Sinai School of Medicine in New York City:

> "In the New Jersey plant one-third of the men had worked for less than three months before quitting; one-third, from three to eleven months; and one-third for one year or more. Of 279 men who worked less than three months, there should have been 3.5 deaths from lung cancer but 13 had occurred as of the time of the study. Of 321 men who worked from three to eleven months, there should have been three or four deaths from lung cancer, but 15 occurred. Of the 333 men who worked for more than one year, there should have been 4 deaths, but 45 occurred. Of the 932 workers, there should have been 50 cancers; 143 occurred."(20)

Ingested Asbestos

Although the effects of inhaled asbestos are reasonably well known, the effects of ingested asbestos have only recently come under study. For example, the high incidence of stomach cancer in Japanese has been linked to their use of rice dusted with talc which usually contains asbestos.(21)

It has been shown by experiments in rats that asbestos fibres can penetrate through the digestive tract and be carried to other organs of the body, accumulating especially in the brain and omentum (tissue surrounding the small intestine). The feeding of large concentrations of asbestos in the diet may cause malignant tumours in the kidney, brain, lymph-nodes and peritoneum of rats and evidently also in baboons.(22) Asbestos-like fibres are widespread. Through ordinary sand filtration 90 percent of the individual fibres can be removed. It is the remaining 10 percent, the very small fibres, which, according to some medical authorities, may present the greatest health hazard over the long term. There is growing concern that these minute fibres may be absorbed from drinking

water through the gastrointestinal tract and into the bloodstream.[23] The picture is by no means clear since a recent report summarizes that evidence which shows short-fibred asbestos dust up to 5 μm in length is not capable of causing fibrosis or cancer.[24]

There are two factors which tend to confuse the effects of ingested asbestos; one, that about 50% of airborne fibres breathed in is cleared from the lungs and subsequently swallowed; and two, that although some of the ingested fibres larger than about 1 μm are excreted within four days, considerable numbers have been found in the gastrointestinal tract even four weeks after the last ingestion. Though the high incidence of gastrointestinal cancer appears traceable to inhaled asbestos, the effects of the amounts of asbestos found in water and food are unclear.[25]

In summary, present knowledge of public health aspects of asbestos in drinking water supplies is inadequate. Legal reactions to the discharge of taconite tailings from Reserve Mining Company differ from each other but agree on the need for eventually stopping the discharge. In his April 20, 1974, Memorandum and Order, Judge Miles Lord stated that "Reserve's discharge creates a serious health hazard to the people exposed to it" (see *Appendix 5*). In staying for 70 days the injunction against further discharges, the U.S. Court of Appeals, Eighth Circuit found that . . . "although Reserve's discharges represent a possible medical danger, they have not in this case been proven to amount to a health hazard. . . . (We) are a court of law, governed by the rules of proof, and unknowns may not be substituted for proof of a demonstrable hazard to the public health" *(Appendix 5).*

While demonstrable hazard is not defined, the Court noted that . . . "even as to workers occupationally exposed to asbestos the time lag of 20 or more years between the date of initial exposure and the onset of cancer in those so exposed . . . " and commented that, " . . . we are sympathetic to the uncertainties facing the residents of the North Shore . . ."[26]

The significance of a 20-year delay following even short-term exposures has been noted earlier in this chapter in connection with epidemiological evidence of deaths due to cancer induced by occupational exposure to asbestos.

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The significance of a 20-year delay following even short-term exposures has been noted earlier in this chapter in connection with epidemiological evidence of deaths due to cancer induced by occupational exposure to asbestos.

TREATMENT AND REMOVAL

Ordinary sand filtration of water supplies removes about 90 percent of the individual asbestos fibres from water supplies. Because of growing concern over the potential public health hazards of asbestos in drinking water, research on treatment and removal is underway by Environment Canada at the Canada Centre for Inland Waters at Burlington, Ontario and by the U.S. Environmental Protection Agency, National Environmental Research Center at Cincinnati, Ohio.

Fibre removal efficiencies of various water treatments have been studied by research scientists and engineers at CCIW.[27] Treatment techniques included simple sand filtration, diatomaceous earth filtration, chemical coagulation or combinations of these depending on the degree of removal required. The most effective method involves chemical coagulation with iron salts and polyelectrolytes followed by filtration. This resulted in better than 99.8% fibre removal from water containing 12×10^6 fibres/litre which was collected about 8km offshore from Silver Bay at 15 to 50m depth. Fibre counting was carried out using the method of Durham and Pang[28] which provided a limit of detectability of 2×10^4 fibres/litre.

TREATMENT AND REMOVAL

DISTRIBUTION OF ASBESTOS IN THE GREAT LAKES

RESEARCH

The first investigations of asbestos fibres in aqueous suspensions were in 1968 when beer samples were centrifuged, ashed and then resuspended in water. Fibres in the residual were examined through electron microscopy and found similar to chrysotile asbestos. The fibres were thought to have come from the asbestos filters used in beer production.(29)

In 1971 similar techniques were used to measure the number of fibres per litre in beverages and drinking water from several Canadian cities. Researchers found that Canadian beer and tap water contained chrysotile asbestos fibres, mostly less than one μm in length, at concentrations ranging from 2 to 10 x 10^6 fibres per litre with unfiltered water supplies at the top of the range. Unfiltered tap water drawn from a lake in the asbestos mining region of Quebec gave a value of 170 x 10^6 per litre.(30)

Distribution In Water

Subsequently, the Ontario Ministry of the Environment assessed the water supplies of municipalities in the Province drawn from surface waters. The first results of this ongoing program were published in 1973.(31) Samples from 22 cities and towns were analyzed by Ontario Research Foundation and the results have recently been published. Concentrations ranged from 0.1 x 10^6 fibres per litre in Ottawa's tap water to 3.9 x 10^6 fibres per litre in Sarnia's. (See Table 8.) Mass concentration was calculated from the number of fibres, their size distribution, and the density of chrysotile (2.4g cm^{-3}).

Figure 2 presents a map published in January 1974(32) showing the fibre counts in the Great Lakes - St. Lawrence River area. Figure 3 is a histogram which shows the frequency with which a particular concentration of fibres occurs. The average concentration is about 1.7 x 10^6 fibres per litre. The locations where counts higher than this are found are along the north shore of Lake Superior between Silver Bay and Duluth (Reserve's discharge); along the St. Clair River; downstream from Montreal and in the asbestos mining district in Quebec. Industries along the St. Clair River and in other locations (Montreal, Toronto) may explain the high counts there. The reason for the higher counts along the Ottawa River is unknown.

During the various Canadian studies, only at Ottawa and Toronto were samples taken by different investigators at different times. Ratio between the counts ranges from about 2 to 14. Ratios in samples taken at Niagara Falls and Thunder Bay in different years range from about 1 to 5. Variability of the counts is within a factor of 2 or 3.(33) Comparisons of the effects of filtration in water treatment plants are available for Toronto, Windsor and Ottawa. In Toronto and Ottawa reduction is from 15 to 25 percent; in Windsor, the reduction was approximately 90 percent. During initial sampling programs by EPA, fibre counts in the water distribution system were sometimes higher than in the raw intake water possibly because of variability in raw water counts and residence time in the system.(34) The average background level of asbestos fibre concentration in water distribution systems in the Great Lakes Basin is 1.6 x 10^6 fibres/litre and 90 percent of the areas test at less than 3 x 10^6.

Continued drinking water sampling programs of the Ontario Ministry of the Environment produced additional May 1974 results. In the Northern Ontario mining/milling area at

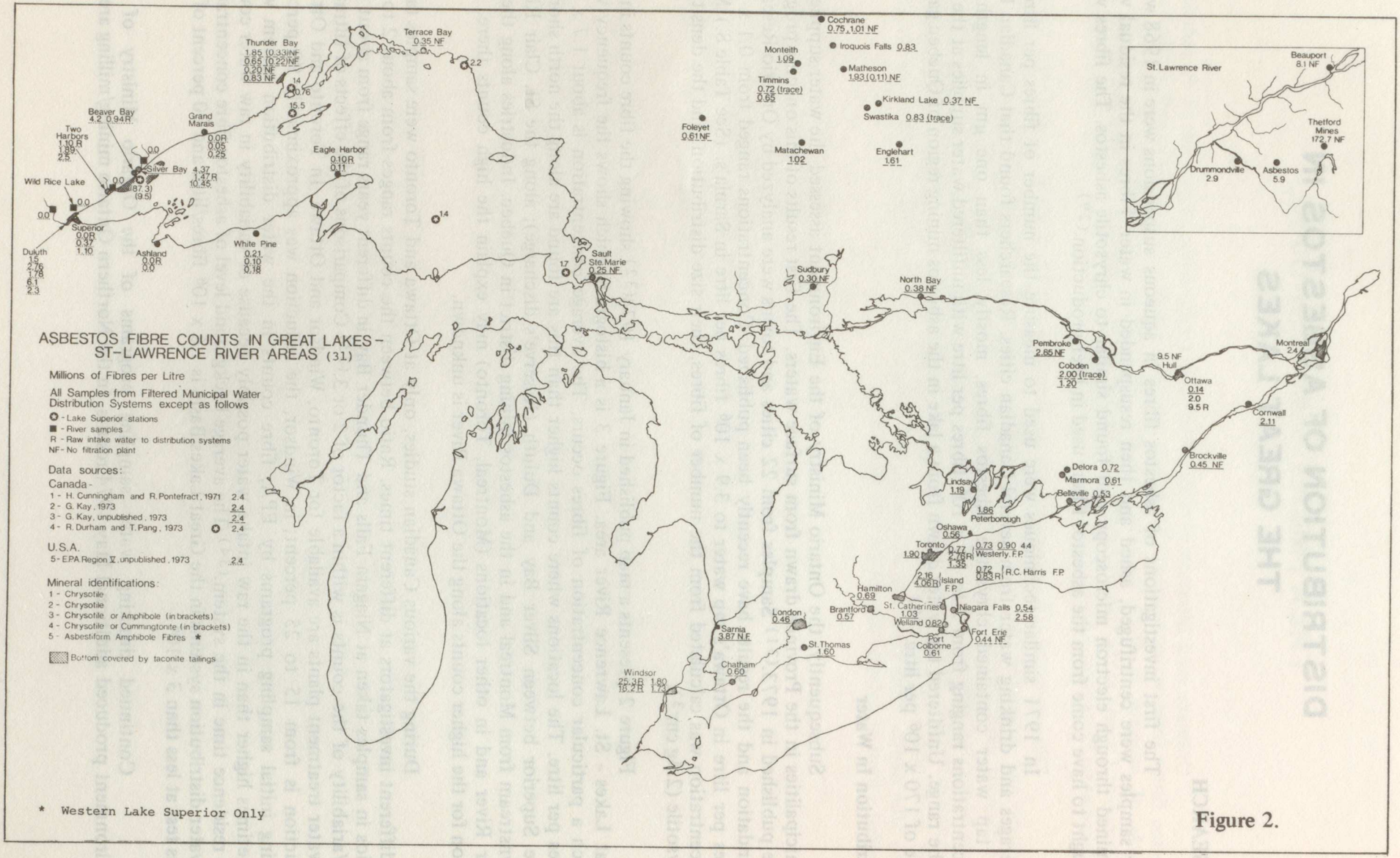

ASBESTOS FIBRE COUNTS IN GREAT LAKES - ST-LAWRENCE RIVER AREAS (31)
Millions of Fibres per Litre
All Samples from Filtered Municipal Water Distribution Systems except as follows
O - Lake Superior stations
■ - River samples
R - Raw intake water to distribution systems
NF - No filtration plant
Data sources:
Canada -
1 - H. Cunningham and R. Pontefract, 1971 2.4
2 - G. Kay, 1973 2.4
3 - G. Kay, unpublished, 1973 2.4
4 - R. Durham and T. Pang, 1973 O 2.4
U.S.A.
5 - E.P.A. Region V, unpublished, 1973 2.4
Mineral identifications:
1 - Chrysotile
2 - Chrysotile
3 - Chrysotile or Amphibole (in brackets)
4 - Chrysotile or Cummingtonite (in brackets)
5 - Asbestiform Amphibole Fibres *
Bottom covered by taconite tailings
* Western Lake Superior Only
Thunder Bay 1.85 (0.33)NF 0.65 (0.22)NF 0.29 NF 0.83 NF
Terrace Bay 0.35 NF
Beaver Bay 4.2 0.94R
Two Harbors 1.10 R 1.89 2.5
Grand Marais 0.0R 0.05 0.25
Silver Bay 4.37 1.47R 10.45
Wild Rice Lake
Superior 0.0R 0.37 1.10
Duluth 1.5 2.76 1.78 6.1 2.3
Ashland 0.0R 0.0
Eagle Harbor 0.10R 0.11
White Pine 0.21 0.10 0.18
Sault Ste. Marie 0.25 NF
Cochrane 0.75, 1.01 NF
Iroquois Falls 0.83
Monteith 1.09
Matheson 1.93 (0.11) NF
Timmins 0.72 (trace) 0.65
Kirkland Lake 0.37 NF
Swastika 0.83 (trace)
Foleyet 0.61 NF
Matachewan 1.02
Englehart 1.61
Sudbury 0.30 NF
North Bay 0.38 NF
St. Lawrence River
Beauport 8.1 NF
Thetford Mines 172.7 NF
Drummondville 2.9
Asbestos 5.9
Pembroke 2.65 NF
Cobden 2.00 (trace) 1.20
9.5 NF Hull
Ottawa 0.14 2.0 9.5 R
Montreal 2.4
Cornwall 2.11
Brockville 0.45 NF
Delora 0.72
Marmora 0.61
Belleville 0.53
Lindsay 1.19
1.86 Peterborough
Oshawa 0.56
Toronto 1.90 0.77 2.76R 1.35
0.73 0.90 4.4 Westerly F.P.
0.72 0.83R R.C. Harris F.P.
2.16 4.06R Island F.P.
Hamilton 0.69
Brantford 0.57
St. Catherines 1.03
Welland 0.82
Niagara Falls 0.54 2.58
Fort Erie 0.44 NF
Port Colborne 0.61
London 0.46
Sarnia 3.87 NF
St. Thomas 1.60
Chatham 0.60
Windsor 25.3R 1.80 16.2R 1.73

Figure 2.

TABLE 8[31]

ASBESTOS FIBRE COUNT (DISTRIBUTION SYSTEM – WATER)

SAMPLE LOCATION	SOURCE	FIBRE COUNT IN MILLIONS PER LITRE	ESTIMATED MASS CONCENTRATION, μg/1
Toronto	L. Ontario	1.90	0.000941
Belleville	Bay of Quinte	0.533	0.000937
Brantford	Grand River	0.570	0.00113
Brockville*	St. Lawrence R.	0.446	0.000602
Chatham	Thames River	0.595	0.00157
Cornwall	St. Lawrence R.	2.11	0.000729
Hamilton	L. Ontario	0.694	0.000154
London	L. Huron	0.456	0.000429
Niagara Falls	Niagara R.	2.58	0.00225
North Bay*	Trout L.	0.384	0.000104
Oshawa	L. Ontario	0.557	0.000159
Ottawa	Ottawa R.	0.136	0.000093
Pembroke*	Ottawa R.	2.85	0.000538
Peterborough	Ottonabee R.	1.86	0.00354
Port Colborne	Welland Ship Canal	0.608	0.000847
Sarnia*	L. Huron	3.87	0.00213
Sault Ste. Marie*	St. Mary's R.	0.248	0.000141
St. Catherines	Welland Ship Canal	1.03	0.00156
Sudbury*	Ramsay Lake	0.297	0.000542
St. Thomas	L. Erie	1.60	0.000500
Thunder Bay*	L. Superior	0.830	0.000235
Welland	Welland Ship Canal	0.820	0.000479

Note: *means No Filtration Plant

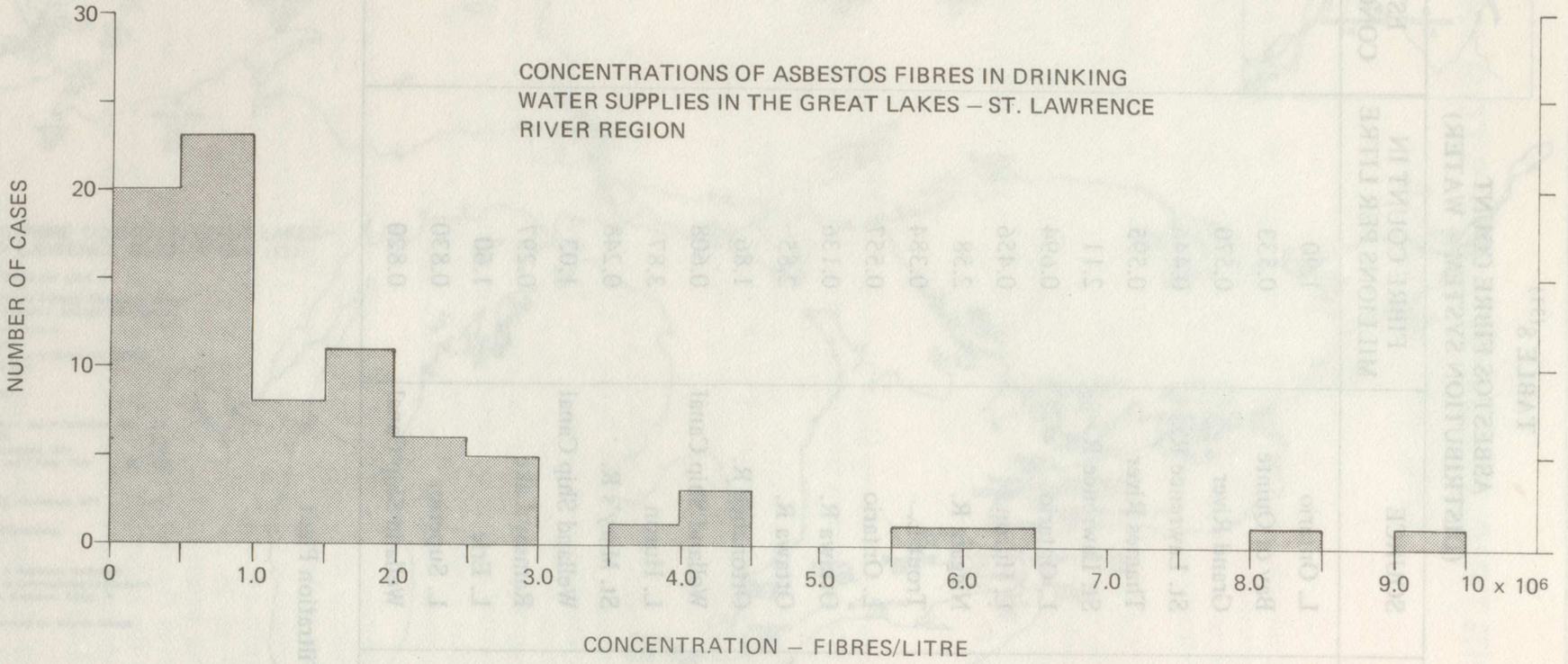


Figure 3. Histogram of asbestos fibre concentration on the Great Lakes – St. Lawrence River region.[32]

Timmins (Mattagami River) untreated water had a concentration of 1.8×10^6 and treated water at 0.26×10^6 concentration. At the Union treatment plant in Leamington on Lake Erie values were 2.2 and 5.2×10^6 (untreated) and 0.96×10^6 (treated). For Blenheim, also on Lake Erie, only an untreated sample value was reported: 1.6×10^6 asbestiform fibres per litre.(35)

The Ontario Research Foundation has carried out many studies on asbestos fibres in liquids, including lake waters, and some beverages. Their microscopy section is engaged in pioneer activity in observing the behaviour of asbestiform fibres. Findings so far indicate there are about 2×10^6 fibres per litre in Great Lakes waters on the average. Asbestos fibres encountered run anywhere from 0.04 to 17 μm in length, with average widths in the 400Å range. The widths are of the right size for cell penetrations to occur.

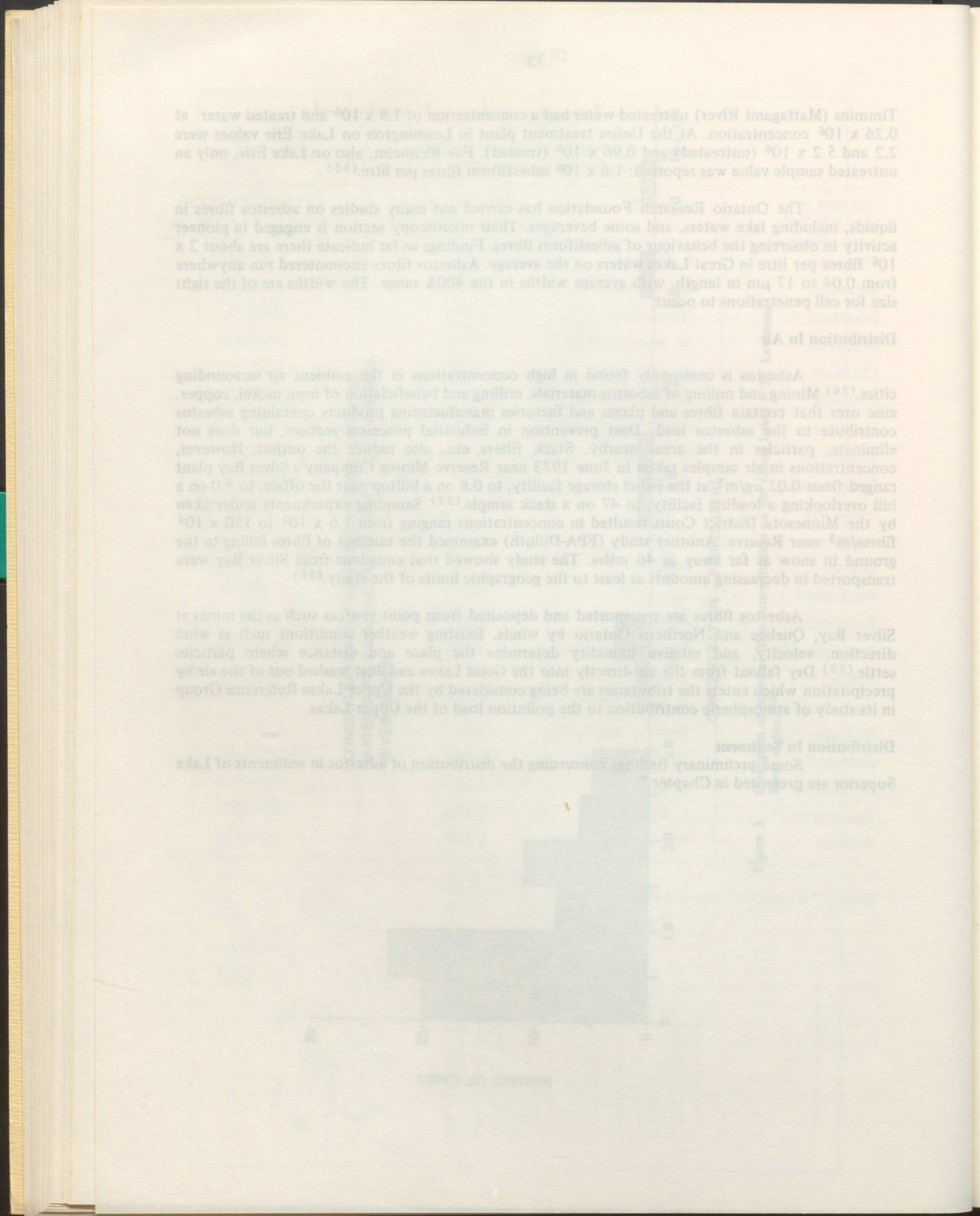
Distribution In Air

Asbestos is commonly found in high concentrations in the ambient air surrounding cities.(36) Mining and milling of asbestos materials, milling and beneficiation of iron, nickel, copper, zinc ores that contain fibres and plants and factories manufacturing products containing asbestos contribute to the asbestos load. Dust prevention in industrial processes reduces, but does not eliminate, particles in the areas nearby. Stack filters, etc., also reduce the output. However, concentrations in air samples taken in June 1973 near Reserve Mining Company's Silver Bay plant ranged from 0.02 $\mu g/m^3$ at the pallet storage facility, to 0.8 on a hilltop near the office, to 5.0 on a hill overlooking a loading facility, to 47 on a stack sample.(37) Sampling experiments undertaken by the Minnesota District Court resulted in concentrations ranging from 1.6×10^3 to 150×10^3 fibres/m^3 near Reserve. Another study (EPA-Duluth) examined the number of fibres falling to the ground in snow as far away as 46 miles. The study showed that emissions from Silver Bay were transported in decreasing amounts at least to the geographic limits of the study.(38)

Asbestos fibres are transported and deposited from point sources such as the mines at Silver Bay, Quebec and Northern Ontario by winds. Existing weather conditions such as wind direction, velocity, and relative humidity determine the place and distance where particles settle.(39) Dry fallout from the air directly into the Great Lakes and dust washed out of the air by precipitation which enters the tributaries are being considered by the Upper Lakes Reference Group in its study of atmospheric contribution to the pollution load of the Upper Lakes.

Distribution In Sediment

Some preliminary findings concerning the distribution of asbestos in sediments of Lake Superior are presented in Chapter 7.



ASBESTOS IN LAKE SUPERIOR

BACKGROUND

Since December 1972, when the first public statement was made of concern over potential public health hazards of asbestos in Lake Superior, a number of detailed investigations of the distribution of asbestos in Lake Superior have been undertaken. While much additional information remains to be developed, enough is at hand to show the general pattern of asbestos occurrence, particularly in the vicinity of the Reserve Mining Company operations at Silver Bay.

ASBESTOS IN LAKE SUPERIOR WATERS

Studies of asbestos in Lake Superior waters particularly at water treatment plant intakes have been made by federal, state, and provincial agencies. Their major findings are summarized below.

Differences in sampling and analytical procedures used by the different agencies have been shown to account for differences in fibre concentrations listed in Tables 6 and 7 in Chapter III. For purposes of this report, it is assumed that within any one reporting agency that analytical differences are minimal. Results of the various studies are therefore presented separately.

U.S. EPA Investigations

Beginning in January, 1974, EPA Region V reported status of research on asbestos in Lake Superior.[40] In most localities chrysotile had been found; whereas, in the western end of Lake Superior amphibole asbestos predominated, but chrysotile was also found. Minor amounts of amphibole asbestos were found at Thunder Bay and in the Timmins-Matheson region of Northern Ontario where chrysotile is mined. This is due to the counter-clockwise circulation pattern which carries amphibole (cummingtonite) fibres from the Reserve Mining Company discharge plant at Silver Bay. None of the rivers flowing into that part of the lake has been shown to contain cummingtonite. This circulation pattern as well as the source of cummingtonite is confirmed by the lack of cummingtonite fibres in any of the other Lake Superior samples and by the similarities in the size distribution in the town of Thunder Bay and in the lake off Silver Bay (Figure 4). It should be noted, however, that minor amounts of amphibole fibres have been found in the Thunder Bay water supply. Recently, the U.S. EPA has reported that daily sampling of the Duluth water supply showed an average 190 μg/1 or 44 x 10^6 fibres/litre of amphibole from March 1973 through January 1974.[41]

Canada Department Of The Environment Study[42,43]

In 1973 the Canada Centre for Inland Waters, Department of the Environment, conducted a preliminary study to evaluate the possibility of transboundary movement of asbestos fibres in Lake Superior. Samples were taken from selected stations during the (previously scheduled) 1973 cruises.

Figure 5 is a map of Lake Superior showing the general location of the sample stations for which results have been obtained. Table 9 shows the results of the analyses of samples from two cruises in early summer of 1973.

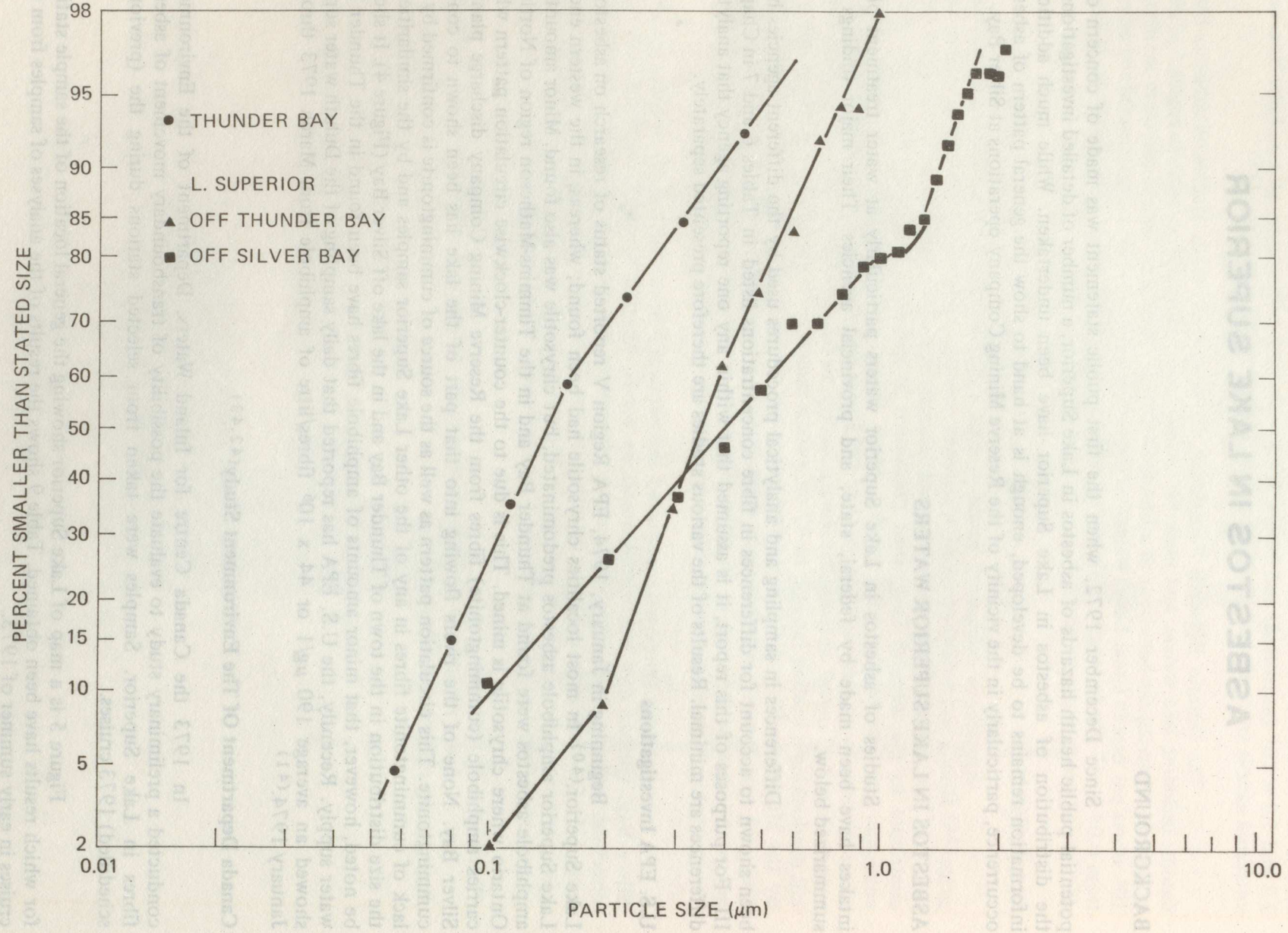


Figure 4. Size distributions of asbestos fibres in selected samples.[32]

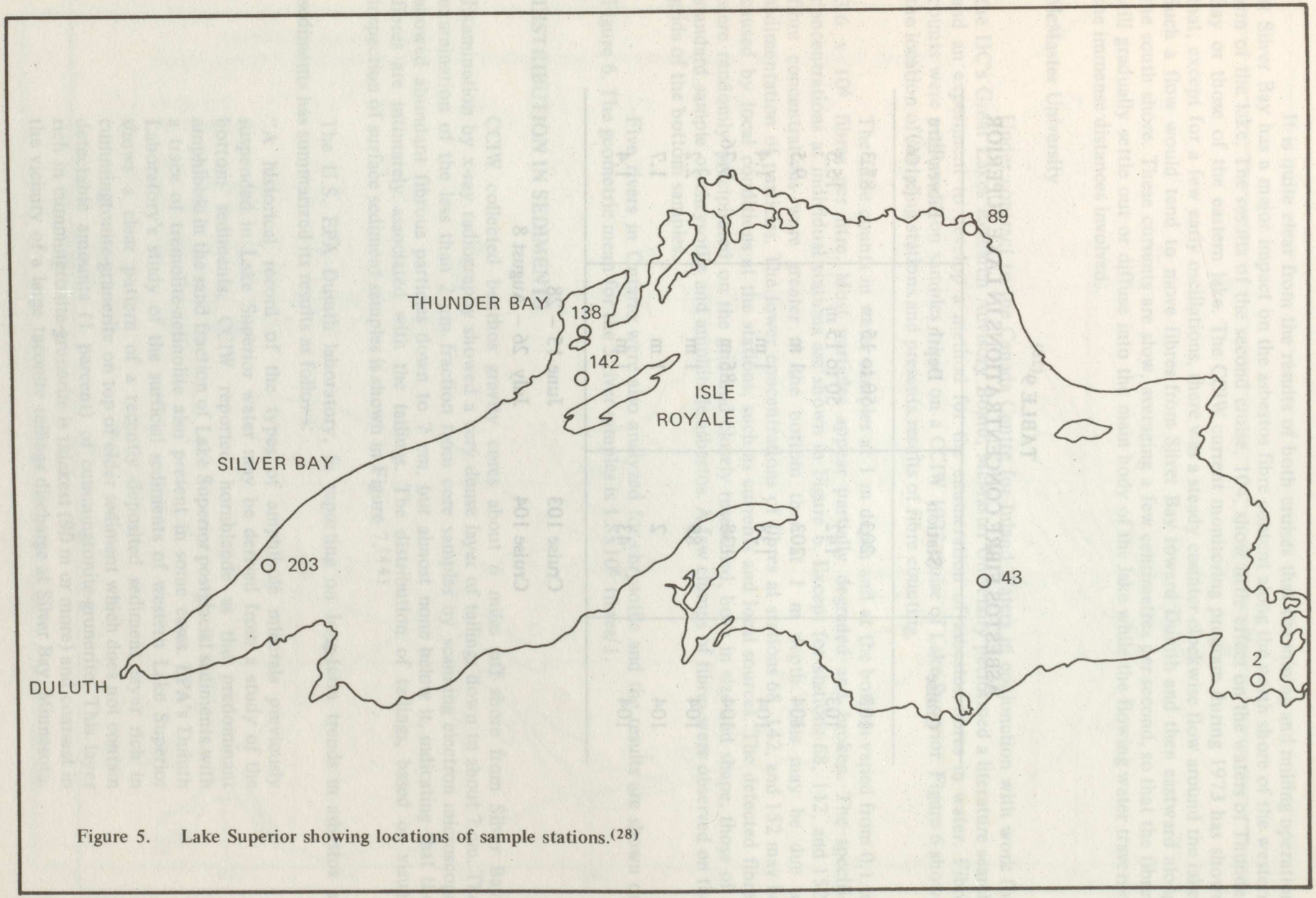


Figure 5. Lake Superior showing locations of sample stations.[28]

TABLE 9[28]

ASBESTOS FIBRE CONCENTRATIONS IN LAKE SUPERIOR

Cruise	Station	Depth	Fibres/litre (x10⁶)
103	203	50 to 15 m	87.3
103	142	50 to 15 m	15.5
104	203	1 m	9.5
104	138	1 m	1.4
104	138	85 m	0.76
104	89	1 m	2.2
104	2	1 m	1.7
104	43	1 m	1.4

Cruise 103 June 15 – 28

Cruise 104 July 26 – August 8

It is quite clear from the results of both cruises that the mining and milling operation at Silver Bay has a major impact on the asbestos fibre content along the north shore of the western arm of the lake. The results of the second cruise, 104, show little effect on the waters of Thunder Bay or those of the eastern lake. The CCIW current monitoring program during 1973 has shown that, except for a few early oscillations, there was a steady counter-clockwise flow around the lake. Such a flow would tend to move fibres from Silver Bay toward Duluth and then eastward along the south shore. These currents are slow, averaging a few centimetres per second, so that the fibres will gradually settle out or diffuse into the main body of the lake while the flowing water traverses the immense distances involved.

McMaster University

Under contract to the Canada Centre for Inland Waters in conjunction with work for the IJC's Great Lakes Research Advisory Board, McMaster University performed a literature search and an experiment to develop a method for the enumeration of asbestos fibres in water. Fibre counts were performed on samples taken on a CCIW 1973 cruise of Lake Superior. Figure 6 shows the location of sampling stations and presents results of fibre counting.

The fibre counts in water samples at 1 m depth and at the bottom varied from 0.1 to 3.6 x 10^6 fibres per litre. Most particles appear partially degraded and broken. The specific concentrations at individual stations are shown in Figure 6. Except for stations 68, 142, and 152, fibre concentrations were greater at the bottom than at 1 m depth. This may be due to sedimentation of particles. The lower concentrations of fibres at stations 68, 142, and 152 may be caused by local conditions at the stations, such as currents and local sources. The detected fibres were randomly precipitated on the grid and closely resembled, both in size and shape, those of a standard sample of chrysotile and amphibole asbestos. A few clumps of fibres were observed on the grids of the bottom samples.

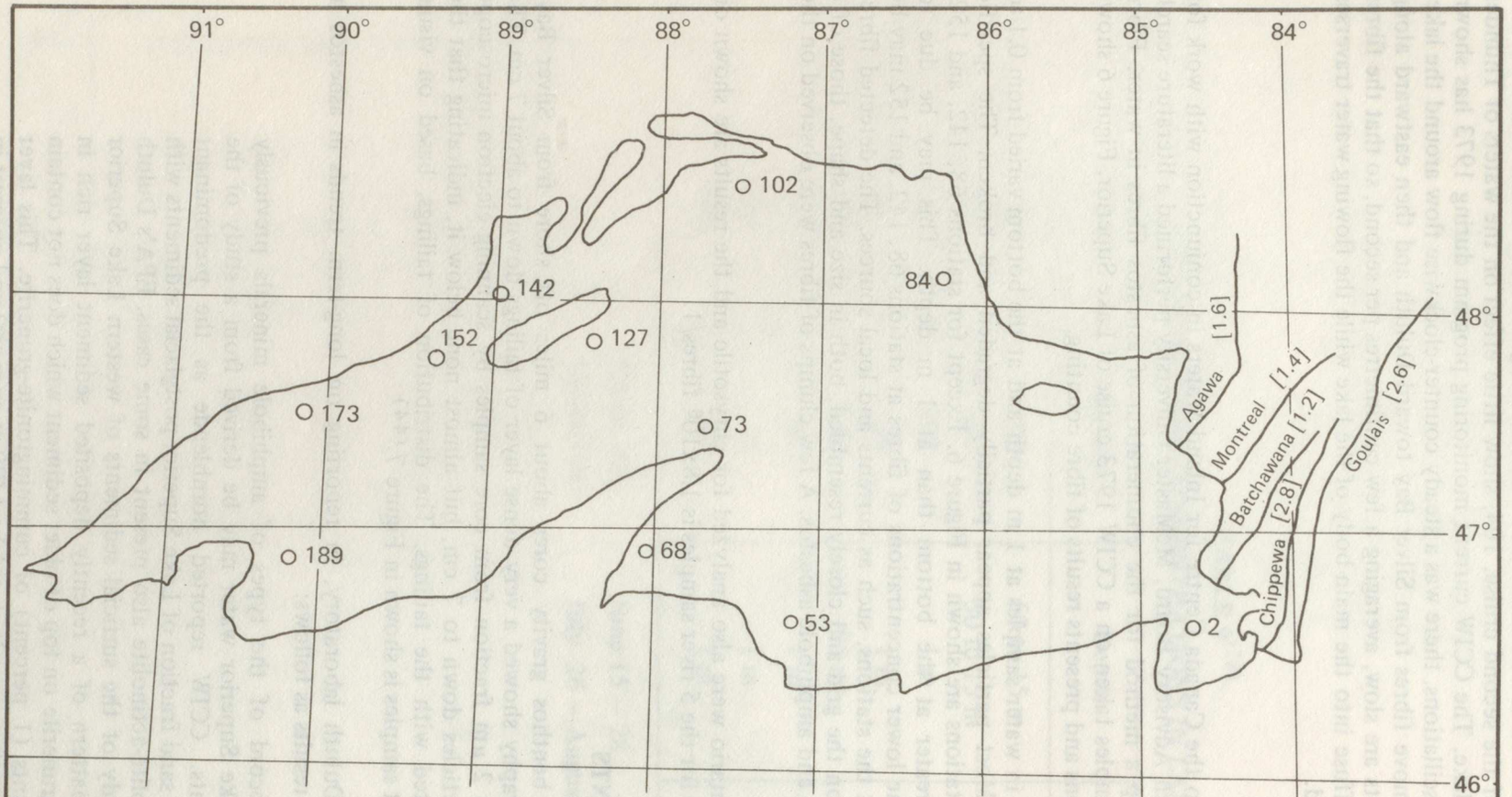
Five rivers in Ontario were also analyzed for chrysotile and the results are shown on Figure 6. The geometric mean for the 5 river samples is 1.8×10^6 fibres/1.

DISTRIBUTION IN SEDIMENTS

CCIW collected benthos gravity cores about 6 miles off shore from Silver Bay. Examination by x-ray radiography showed a very dense layer of tailings down to about 7 cm. The examination of the less than 2 μm fraction from core samples by scanning electron microscope showed abundant fibrous particles down to 7 cm, but almost none below it, indicating that the fibres are intimately associated with the tailings. The distribution of tailings, based on visual inspection of surface sediment samples is shown in Figure 7.[44]

The U.S. EPA Duluth laboratory, in reporting on long-term trends in asbestos in sediments has summarized its results as follows:

> "A historical record of the types of amphibole minerals previously suspended in Lake Superior water may be derived from a study of the bottom sediments. CCIW reported hornblende as the predominant amphibole in the sand fraction of Lake Superior postglacial sediments with a trace of tremolite-actinolite also present in some cases. EPA's Duluth Laboratory's study of the surficial sediments of western Lake Superior shows a clear pattern of a recently deposited sediment layer rich in cummingtonite-grunerite on top of older sediment which does not contain detectable amounts (1 percent) of cummingtonite-grunerite. This layer rich in cummingtonite-grunerite is thickest (90 m or more) and coarsest in the vicinity of a large taconite tailings discharge at Silver Bay, Minnesota.



Station No.	2	53	68	73	84	102	127	142	152	173	189
Fibrecounts at 1 m depth ($x10^6/l$)	1.0	2.5	3.5	1.1	0.7	1.5	1.2	2.2	1.1	1.0	1.7
at the bottom ($x10^6/l$)	1.6	3.6	3.0	2.8	1.3	2.3	2.3	1.6	0.9	1.6	1.9

NOTE: Counts of asbestiform fibres in rivers entering eastern Lake Superior are for chrysotile fibres. The other counts are for amphibole fibres.

Figure 6. Station sampling locations in Lake Superior during CCIW cruise 73-108 (5)

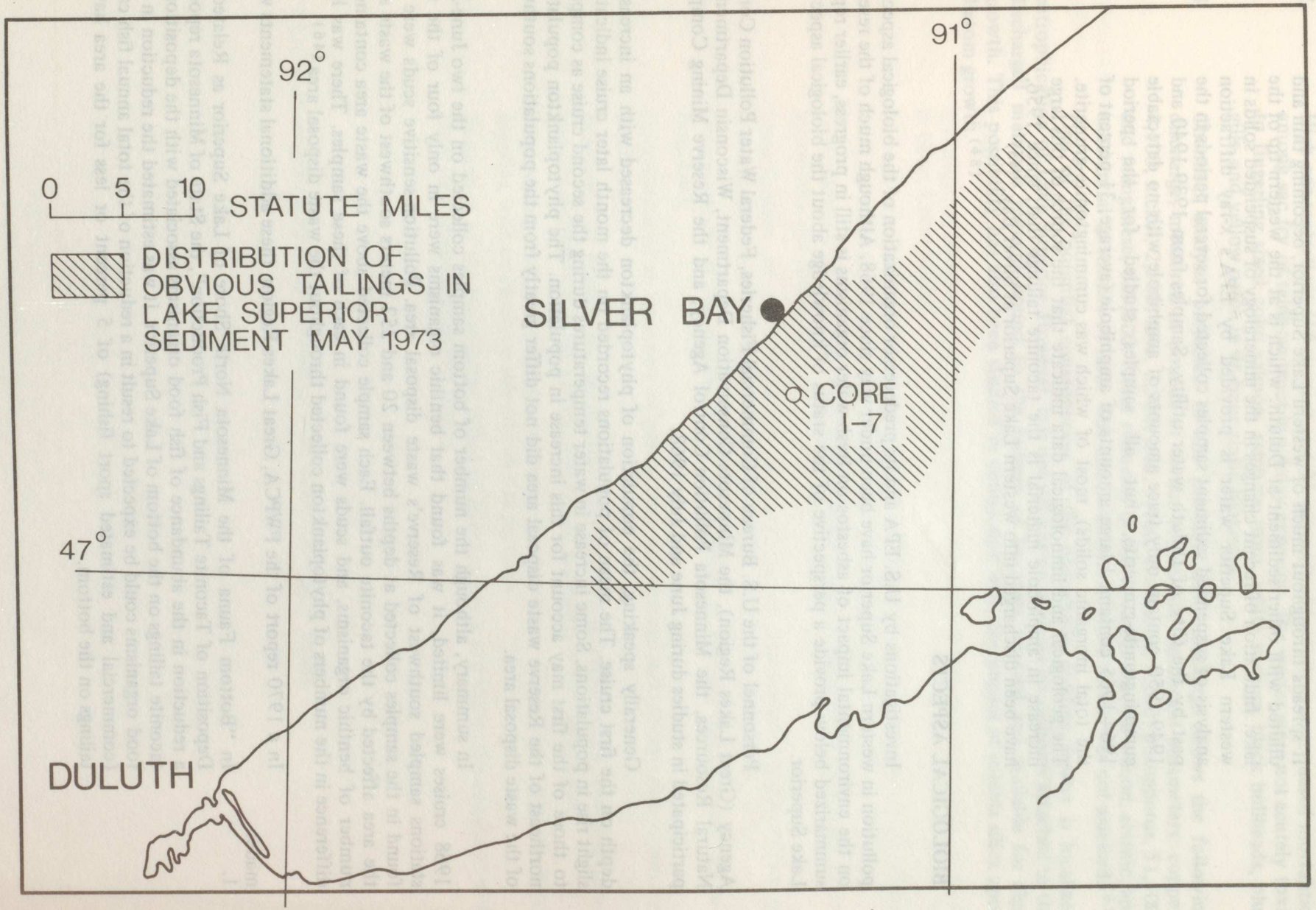


Figure 7. Distribution of taconite tailings in Lake Superior sediment based upon visual examination of surface sediment samples[44]

It spreads throughout much of western Lake Superior, becoming thin and diluted with other sediment at Duluth, which is at the western tip of the lake. Indication of recent changes in the mineralogy of suspended solids in western Lake Superior water is provided by EPA's x-ray diffraction analysis of suspended sediment samples collected for several periods in the past by the City of Duluth water utility. Samples from 1939-1940 and 1949-1950 contain only trace amounts of amphibole with no detectable cummingtonite-grunerite, but all samples studied for the period 1964-1965 contained large amounts of amphibole (average, 31 percent of the total inorganic solids), most of which was cummingtonite-grunerite. The geological and limnological data indicate that the source of this large increase in amphibole material is the taconite tailings that, since 1956, have been discharged into western Lake Superior at Silver Bay."(45)

BIOLOGICAL ASPECTS

Investigations by U.S. EPA and its predecessor organization of the biological aspects of pollution in western Lake Superior have been under way since 1968. Although much of the research on the environmental impact of asbestos on fresh-water organisms is still in progress, earlier reports summarized below provide a perspective of the status of knowledge about the biological aspects of Lake Superior.

Personnel of the U.S. Bureau of Commercial Fisheries, Federal Water Pollution Control Agency (Great Lakes Region), the Minnesota Conservation Department, Wisconsin Department of Natural Resources, the Minnesota Pollution Control Agency, and the Reserve Mining Company participated in studies during June and July 1968.

Generally speaking, the population of phytoplankton decreased with an increase in depth on the first cruise. The mean of populations recorded on the month later cruise indicated a slight rise in populations. Some increase in water temperatures during the second cruise as compared to those of the first may account for this increase in population. The phytoplankton populations northeast of the Reserve waste disposal area did not differ greatly from the populations southwest of the waste disposal area.

In summary, although the number of bottom samples collected on the two June-July 1968 cruises were limited, it was found that benthic organisms were in only four of the nine stations sampled southwest of Reserve's waste disposal area. Pollution-sensitive scuds were not found in the samples collected at depths between 20 and 252 meters southwest of the waste area, the area affected by the taconite outfall. Each sample collected above the waste area contained a number of benthic organisms, and scuds were found in each of these samples. There was little difference in the numbers of phytoplankton collected throughout the waste disposal area.(46)

In a 1970 report of the FWPCA, Great Lakes Region, these additional statements were made:

1. In "Bottom Fauna of the Minnesota North Shore of Lake Superior as Related to Deposition of Taconite Tailings and Fish Production", the State of Minnesota reported a reduction in the abundance of fish food organisms associated with the deposition of taconite tailings on the bottom of Lake Superior. It was estimated the reduction in fish food organisms could be expected to result in a reduction of the total annual fish catch (commercial and estimated sport fishing) of 5 percent or less for the area having tailings on the bottom.

2. High concentrations (10 percent and 25 percent) of taconite wastes caused mortalities among sac fry of rainbow trout in a 4-day exposure. The wastes were not acutely toxic to fingerling sized coho salmon, rainbow trout, white suckers, black bullheads, blue gills, and yellow perch in 96-hour static bioassays.

3. Chemical analysis projected to the probable daily discharge shows the following discharge, measured in pounds of certain biologically significant parameters: copper, 4,100; nickel, 2,500; zinc, 2,500; lead, 5,100; chromium, 6,200; phosphorus, 51,500; and manganese, 629,000. Other elements in the discharge include silicon, arsenic, and substantial quantities of iron. The chemical state of these metals was not assessed.[47]

One of the potential consequences of the phosphorus loading figures is localized eutrophication of Lake Superior. However, it is not yet known whether phosphorus attached to the discharged materials remains bound to the tailings or becomes released and available for algal growth. This possibility has also been studied in connection with the impact of soluble silica upon diatom growth.[48]

RESEARCH NEEDS

There are needs for a variety of expanded research efforts in the analytical, environmental, and public health aspects of asbestos in the Great Lakes. Specific research needs include:

1. Improvement of analytical procedures for identification and enumeration of asbestos fibres.
2. Determination of public health effects of asbestos fibres in drinking water.
3. Investigation of the manner in which asbestiform minerals weather and go into solution in Great Lakes waters.
4. Determination of asbestiform minerals in air and water with particular emphasis on drinking water supplies.
5. Determination of short and long term effects, if any, of such fibres on aquatic biota, microbiota and animal life.
6. Identification of the magnitude and sources of atmospheric contributions of asbestiform minerals to Great Lakes waters.
7. Determination of the significance of resuspension of asbestos from lake-bottom and from land.
8. Compilation of an inventory of production, use, disposal and ultimate fate of asbestos products.
9. Evaluation of present and predicted future levels of asbestos species, concentrations, and size distribution in air, surface waters, and sediments in the Great Lakes.
10. Improvement of the efficient removal of asbestiform fibres from drinking water supplies, with emphasis on sub-micron size particles.
11. Evaluation of the potentiating effect of asbestos fibres and the metals associated with them by pathogens including viruses.

*1,2,5,7 and 9 are under study at the EPA National Water Quality Laboratory - Duluth.

RECOMMENDATIONS AND CONCLUSIONS

1. There are problems with asbestos counting and identification methods. Some action has been taken by U.S. EPA and Canadian agencies to develop more reliable counting and identification procedures. The Standing Committee on Analytical Sampling and Measurement Methods of the Great Lakes Research Advisory Board has been asked to recommend standard methods.

2. Because of the potential hazards of asbestiform fibres to human health, sampling programs are continuing to be initiated. The concensus appears to be that neither country can afford to wait for the single best analytical methodology or the solution of quality control problems. Large scale new programs should be limited until some solutions are found and more knowledge of the actual health effects of asbestiform fibres has been gained. Such knowledge would include defining the relationship between fibre length and degree of hazard.

3. Public health hazards and hazards to aquatic organisms resulting from ingestion of asbestos are predicted but scientists are not in agreement on hazards resulting from ingestion. Additional research along the lines outlined under "Research Needs" should be supported by the federal, provincial and state governments concerned.

4. U.S. Environmental Protection Agency and the Department of the Environment's Canada Centre for Inland Waters studies of Lake Superior indicate that there is likely transboundary pollution from asbestos in Lake Superior. It is recommended that this possible transboundary movement be further characterized and possibly quantified in the IJC Upper Great Lakes Reference Studies.

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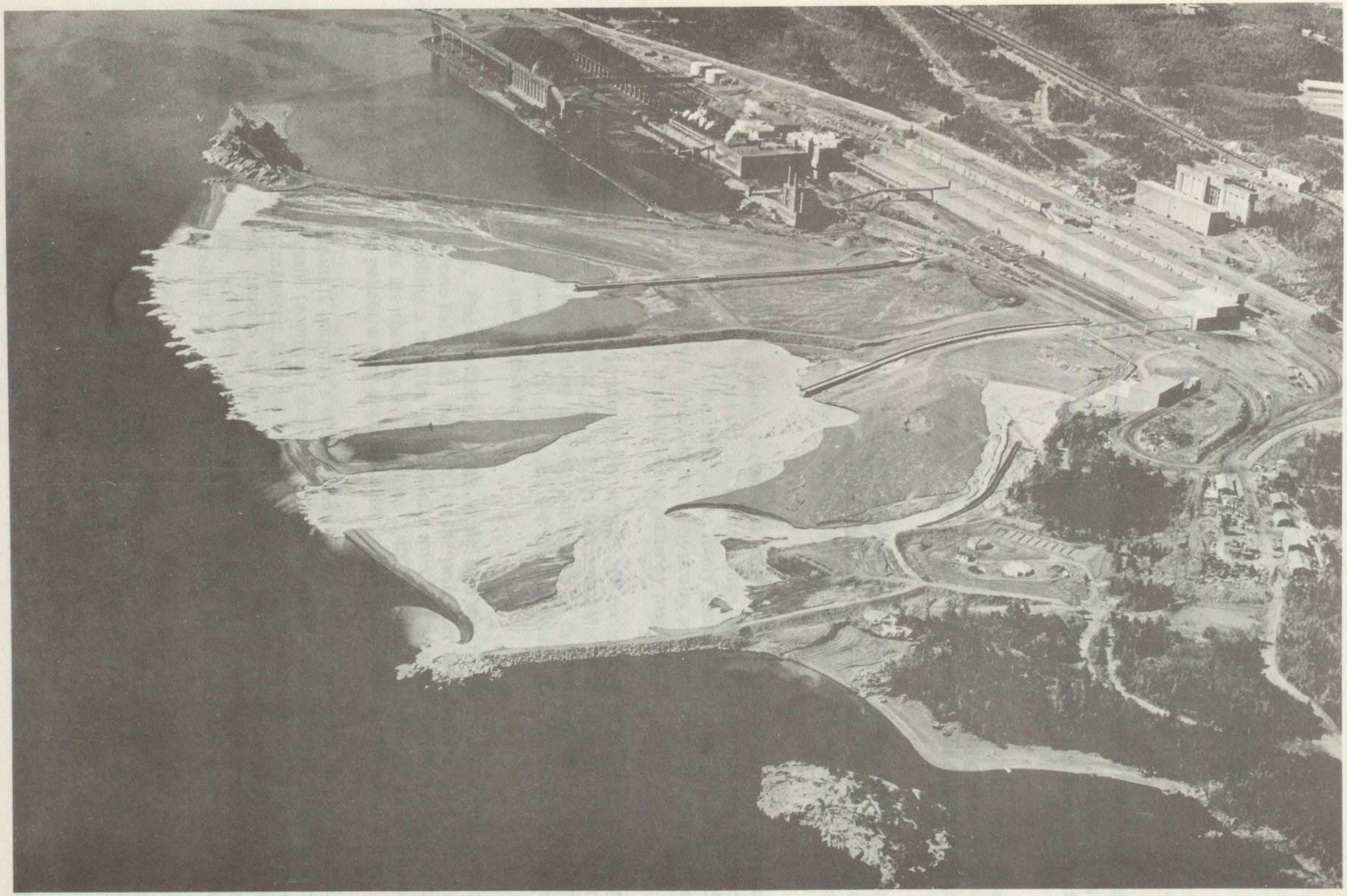
APPENDICES

APPENDICES



Reserve Mining Company Taconite Tailings Discharge (Basgen Photography, Duluth, Minnesota)

APPENDIX 1
TACONITE MINING, BENEFICIATION, AND WASTE DISPOSAL

The history of taconite mining is the history of the recovery of the iron-mining industry at a time when high grade hematite ores were becoming scarce. It is the story of a new offshoot industry—taconite beneficiation. Taconite is hard, well-cemented, ferruginous chert and slate.

As the natural iron ores were being depleted, much research was conducted on processes to beneficiate the low grade and very hard taconite. Beneficiation upgrades the taconite from material containing twenty-five to thirty percent iron to material containing as much as sixty-five percent or more iron.

The search for ways to mine and concentrate taconite began before 1920, and did not culminate until after 1950, when Reserve Mining Company and Erie Mining Company pioneered commercial size plants for the manufacture of taconite pellets. At that point, taconite beneficiation proved economically feasible.

In taconite processing plants, taconite is crushed and ground so that over ninety percent of the material is less than 325 mesh; that is, finer than flour. This is necessary because iron and silica, the principal constituents of taconite, are so finely grained and intimately associated that only after grinding this finely are the grains of iron physically separable from the grains of silica. The iron grains can then be separated from the silica grains by magnets.

Although the principle is admittedly simple, the technology of grinding, handling, and processing so fine a material is extremely difficult and complicated. A large quantity of water is used in the process, both for continual washing and sizing of the material, and as a medium for handling it. It is the voluminous use of water and the state in which it is left, as well as where it is then disposed, that concerns environmentalists.

The extremely fine particles of high grade iron are finally converted to iron oxide pellets of approximately one-half inch diameter. In the pelletizer the magnetic dust is first made into "green" pellets by rolling a mixture of bentonite mud and magnetic grains in a large revolving drum. The "green" pellets are then heated to about 2,400 degrees Fahrenheit in a kiln where they are converted to taconite pellets, a very desirable blast furnace feed which is easily handled.

Reserve Mining Company's ore deposits lie on the eastern edge of the Mesabi Iron Range. In processing Mesabi taconites, about three tons of crude, well-cemented magnetic taconite containing five percent magnetic iron are mined, crushed, ground and concentrated to iron oxide pellets in a kiln. In the process up to 10,000 gallons of water is used for each ton of pellets produced. Waste tailings, left after the iron grains are pulled by the magnet from the crushed taconite ore, are produced at the rate of about two million tons for every one million tons of concentrated pellets.

On December 18 and 22, 1947, the Minnesota Department of Conservation and the Water Pollution Control Commission, respectively, granted permits to Reserve Mining subject to a number of conditions, some of which are the following:

- The tailings were to include no oil.
- The tailings were not to include any material quantities of matter soluble in water.

- The tailings were not to be discharged so as to result in any material clouding or discoloration of the water outside the approximately nine square mile zone.
- The tailings were to have no material adverse effects on fish.
- The tailings were not to cause any material unlawful pollution of Lake Superior.
- The tailings were to have no material adverse effects on public water supplies.
- The tailings were not to result in any nuisance outside the approximately nine square mile zone.

The permits provided that if any of the conditions were violated, the permits were subject to revocation.

In 1956 Reserve sought to amend its permits. On July 6, 1956, without any hearing, the Commissioner of Conservation granted an amendment to allow an increased appropriation of water from 130,000 gallons per minute to 260,000 gallons per minute. The Water Pollution Control Commission allowed the increase after a public hearing.

In 1960 Reserve again required an increase in the amount of water it was allowed to use and return to the lake. On July 13, 1960, a hearing was held by the Water Pollution Control Commission, and on September 8, 1960, the Commission granted the amendment which in effect doubled the water use and discharge to 502,000 gallons per minute.

In January 1970 the Reserve Mining Company filed an appeal from the adoption of WPC 15, Minnesota's interstate water quality standards. The Minnesota Pollution Control Agency (MPCA) then cross-filed for an injunction to enjoin Reserve from violating the terms of WPC 15. Specifically at issue was WPC 15 (c) (6) which requires secondary treatment, or the equivalent, for all waste discharges. This section further includes an effluent standard, in part, of 30 mg/1 total suspended solids. The Reserve Mining Company discharge contains approximately 28,000 mg/1 total suspended solids. Reserve Mining Company was also contending WPC 15 (a) (4) or the anti-degradation clause. The court ruled that WPC 15 (c) (6) which provides for secondary treatment of industrial wastes to be unreasonable, arbitrary, and capricious as applied to Reserve. The court also held that the anti-degradation clause was inapplicable to Reserve and that it applied to dischargers which are new or expanded after the date of adoption. The court then granted Reserve a variance. The MPCA appealed the ruling to the Minnesota Supreme Court which in August 1972 upheld in part the lower court's ruling, but in part also reversed that ruling. The Supreme Court ruled that the lower court exceeded its authority in granting Reserve a variance and remanded the case back to the lower court with instructions to remand the case back to the MPCA for a hearing on any request for a variance by the Reserve Mining Company. The MPCA is currently a party in the Reserve Mining v. United States suit.

On January 16, 1969, the Secretary of the Interior called a conference in the matter of pollution of the waters of Lake Superior and its tributary basin. The conference met on May 13-15 and September 30 - October 1, 1969; April 29-30 and August 12-13, 1970, and January 14-15 and April 22-23, 1971. Through the conference mechanism the Reserve Mining Company was requested to undertake engineering and economic studies relating to possible ways and means of reducing by the maximum practicable extent the discharge of tailings to Lake Superior and to submit a series of engineering studies to the conference. At the January 14-15, 1971 conference session, Reserve submitted its preliminary plan "Plan to Modify Tailings Discharge System." At the April 22-23, 1971 conference session, the conference concluded that the Reserve Mining Company plan was unacceptable and the conference chairman indicated that he would recommend to the Administrator of the Environmental Protection Agency that proceedings under Section 10 (c) (5) of the Federal Water Pollution Control Act be initiated.

On April 28, 1971, the EPA served notice to the Reserve Mining Company that the company operations located on and discharging effluent into Lake Superior are responsible for violation of established State and Federal water quality standards, thus constituting a 180-day notice. No agreement was reached between the EPA and the Reserve Mining Company during the 180-day period and on January 19, 1972, the Administrator of the Environmental Protection Agency asked the Department of Justice to file suit against the Reserve Mining Company to halt pollution of Lake Superior by Reserve's ore processing plant at Silver Bay, Minnesota. In February 1972, a civil action was filed by the Justice Department in the U.S. District Court for the District of Minnesota. The suit was filed on the basis of violation of intrastate water quality standards, violation of interstate water quality standards, and violation of the Refuse Act of 1899. A common nuisance court was added later. The trial commenced August 1, 1973, in the U.S. District Court, Minneapolis. The court's findings reported in April 1974 were appealed to the Eighth Circuit whose findings are presented in Appendix 5.

Source: Superior Polluter, Save Lake Superior Association and Northern Environmental Pollution Council, Duluth, Minnesota, October 1972.

APPENDIX 2

CHRONOLOGY OF THE RESERVE MINING CASE

1951 – Reserve Mining Company begins test operation of taconite processing facility at Silver Bay, Minnesota.

1955 – Reserve Mining Company begins commercial operation of Silver Bay taconite processing plant. Production capacity is 3,750,000 tons of iron ore pellets annually.

1960 – Added facilities increase Silver Bay plant's annual production capacity to six million tons of iron ore pellets.

1964 – Production capacity reaches 9,600,000 tons annually.

1966 – Capacity increases to 10,800,000 tons.

January 16, 1969 – U.S. Department of the Interior report (Stoddard Report) recommends that Corps of Engineers allow Reserve Mining to discharge its taconite wastes into Lake Superior for no longer than three years.

September 29, 1969 – Studies by National Water Quality Laboratory show conclusively that taconite tailings discharged into Lake Superior at Silver Bay, Minnesota, are being carried by lake currents into Wisconsin waters. Tailings are found in water supplies of Grand Marais, Beaver Bay, Two Harbors, and Duluth. No tailings are found in sediment samples taken at Duluth water plant.

September 30, 1969 – Federal Water Pollution Control Administration announces that taconite tailings from Reserve Mining Company's Silver Bay plant have deleterious effect on ecology of Lake Superior by reducing organisms necessary to support fish life.

November 26, 1969 – Secretary of the Interior approves Minnesota interstate water quality standards.

December 24, 1969 – Reserve files appeal from water quality standards in Lake County Court, Minnesota.

January 9, 1970 – Federal Water Pollution Control Administration's National Water Quality Laboratory initiates water quality monitoring program on Lake Superior.

February 1970 – Minnesota Pollution Control Agency files suit against Reserve Mining Company charging violation of basic state anti-pollution law and of state's interstate water quality standards.

February 13, 1970 – Secretary of the Interior, Walter Hickel, asks U.S. Army Corps of Engineers to issue a conditional three year revalidation of Reserve Mining Company's permit to discharge taconite tailings into Lake Superior.

December 1970 – Sixth Judicial District Court of Minnesota finds "the continuance of the present method of discharge for any substantial period of time . . . is intolerable and that substantial modifications must be put into effect."

December 23, 1970 – Executive Order of the President (No. 117474) orders establishment of the Refuse Act Permit Program (RAPP).

January 15, 1971 – Reserve Mining Company announces plans to continue to discharge taconite wastes into Lake Superior, but says it will invest $49 million over the next 20 years to keep waste on the lake bottom.

March 5, 1971 – Governor Anderson requests Corps of Engineers to deny Reserve's RAPP permit and issue a conditional permit requiring on-land disposal.

April 22 – 23, 1971 – Chairman of the Federal Enforcement Conference at Duluth recommends that EPA initiate proceedings against Reserve under Section 10 (c) (5) of the Federal Water Pollution Control Act.

April 28, 1971 – EPA issues 180-day notice for Reserve Mining Company to stop polluting interstate waters of Lake Superior.

May 15, 1971 – Corps refuses Governor Anderson's request stating that EPA's actions pre-empted the Corps.

January 19, 1972 – EPA asks Justice Department to file suit against Reserve Mining Company to halt discharge of taconite into Lake Superior at Silver Bay, Minnesota.

February 17, 1972 – Justice Department files suit in Federal District Court in Minneapolis, Minnesota, against Reserve Mining Company to abate pollution of Lake Superior from taconite tailing discharges of 67 thousand tons per day. EPA says that presence of trace mineral cummingtonite in the Wisconsin portion of the lake shows interstate pollution. (Case was filed under the 1899 Refuse Act.)

March 13, 1972 – State of Michigan files motion to intervene in Federal suit against Reserve Mining Company. (Filed in U.S. District Court in Duluth.)

March 16, 1972 – State of Wisconsin files motion to intervene in Federal suit against Reserve Mining Company. (Filed in Duluth.)

April 6, 1972 – Lake County, Minnesota, files motion in U.S. District Court at Duluth to intervene on behalf of Reserve Mining Company.

December 7, 1972 – Arlene Lehto questions asbestos fibres relationship to cancer at IJC Duluth hearing.

Week of May 14, 1973 – Drs. Gary Glass and Phillip Cook and National Water Quality Laboratory Director, Dr. Donald Mount, establish relationship between asbestos and cummingtonite in that both have same characteristics.

June 1973 – Minnesota Pollution Control Agency receives the University of Wisconsin (Stephen Burrell) report on amphiboles in taconite from Reserve's Peter Mitchell mine in Babbitt, Minnesota, tracing the persistence of the amphibole minerals from the bedrock, through the mill into the Lake Superior discharges and into the air.

June 6, 1973 – Dr. Mount calls Francis Mayo, Administrator of Region V of EPA, on the situation and emphasizes the need to look at the public health aspects of the situation. Dr. Irving Selikoff, authority on asbestos effects research, is retained to study relationships further.

June 8, 1973 – Focus of the Reserve controversy begins to shift to the public health impact of the discharge into the air and water.

June 15, 1973 – Trial Judge Miles Lord says that release of information to public concerning the asbestos problem will not affect his ruling in the case. Judge Lord, on a conference call with Dr. Selikoff, hears the latter express concern for air pollution problem.

June 15, 1973 – EPA announces that its National Water Quality Laboratory has found high concentrations of asbestos-like fibres in drinking water supply at Duluth and several other communities on the Minnesota shore of Lake Superior. Source is believed to be taconite tailings discharged by Reserve Mining Company at Silver Bay.

June 16, 1973 – EPA establishes Field Operations Center (FOC), to be headquartered at National Water Quality Laboratory. Louis Breimhurst, Director of EPA's Minnesota – Wisconsin District Office, named to head FOC.

June 16, 1973 – EPA recommends that bottled water be made available for children up to five years old. Local dairies, bottled water suppliers, and soft drink bottlers are contacted to insure that a gallon of "safe water" is available daily for each of Duluth's estimated 10,000 children in this category.

June 17, 1973 – Officials of Lake Superior's north shore communities are briefed on the asbestos situation. Briefers include officials from EPA, Minnesota Pollution Control Agency, Minnesota State Health Department, St. Louis County, and the Governor's Office.

June 17, 1973 – Civil Defense Office locates and provides 5,000 half-gallon containers for local dairy to begin bottling of safe drinking water.

June 17, 1973 – Dr. Irving Selikoff, authority on asbestos effects research, arrives in Duluth with team of scientists from Mt. Sinai Hospital, New York City. Team collects water and human tissue samples to make preliminary determination of effects, in humans, of ingested asbestos from water supply.

June 18, 1973 – EPA officials brief House Public Works Committee on Duluth situation.

June 20, 1973 – President Nixon appoints Russell Train, Chairman of the Council on Environmental Quality, to coordinate all Federal efforts to resolve the asbestos problem at Duluth.

June 21, 1973 – U.S. Army Corps of Engineers flies mobile water filtration unit from Ft. Belvoir, Virginia, to Duluth. Unit is set up at National Water Quality Laboratory to determine whether equipment will remove asbestos fibres from city's water supply.

June 30, 1973 – Office of Economic Opportunity provides a $100,000 grant to supply bottled water to residents of Duluth.

August 1, 1973 – U.S. District Court, Minneapolis, added a common nuisance count to action in Reserve Mining case.

February 5, 1974 – Judge Miles Lord of the U.S. District Court for the District of Minnesota states "there has been a *prima facie* case of a public health threat by the discharge (of Reserve Mining) into the air and water."

February 8, 1974 – Judge Miles Lord indicates that a serious health hazard does exist in the discharges of the Reserve Mining Company.

Early April 1974 – A negotiation session between the plaintiffs and the defendents is held (17 members).

April 20, 1974 – Judge Miles Lord orders Reserve to stop discharge the following day.

April 21, 1974 – Reserve shuts down its Silver Bay, Minnesota facility at 12:01 p.m.

April 22, 1974 – A three judge panel at an evening hearing of the U.S. Court of Appeals, Eighth Circuit, grants Reserve a stay of the temporary injunction until August 14.

April 1974 – EPA Administer Russell Train states that the case against Reserve should be pursued to the Supreme Court to protect the health of persons whose water is being contaminated by the discharge.

May 8, 1974 – The plaintiffs of the U.S., Michigan, Wisconsin, etc. were requested with the entire circuit court to hear segments on May 15.

May 11, 1974 – Judge Lord submits a 109-page supplemental memorandum to the U.S. Court of Appeals, Eighth Circuit, expanding his April 20th opinion.

May 15, 1974 – The U.S. Court of Appeals, Eighth Circuit, takes under advisement Reserve's motion to allow its plant to remain open pending full appeal of the case.

June 4, 1974 – A 70-day stay of injunction is granted to Reserve by U.S. Court of Appeals, Eighth Circuit.

June 25, 1974 – Minnesota Pollution Control Agency requests support of the U.S. Attorney General, William B. Saxbe, for appeal to Supreme Court.

July 10, 1974 – The U.S. Supreme Court refuses to reinstate Judge Lord's order to stop the Reserve discharge.

July 16, 1974 – President's Council on Environmental Quality urges prompt and expedited appeal of Eighth Circuit Court of Appeals decision.

July 31, 1974 – Reserve and four other northeastern Minnesota taconite mining firms are closed at midnight by United Steelworkers strike.

August 3, 1974 – Judge Lord tells the U.S. Court of Appeals, Eighth Circuit, that Reserve and its parent companies, Armco and Republic, still have not shown good faith in trying to negotiate a site for an on-land disposal system. (Since no plan was submitted, Judge Lord told the Court that the District Court therefore could not recommend a continuation of the June 4, 1974, stay issued by the appellate court.)

September 3, 1974 – Minnesota files briefs requesting fines of $73 million for air and water discharges.

September 6, 1974 – Minnesota Pollution Control Agency again votes to seek review by Supreme Court.

October 4, 1974 – Justice Department urges Supreme Court to end stay order allowing continued operation of Reserve Mining.

October 11, 1974 – U.S. Supreme Court refuses to halt Reserve's discharge.

November 1974 – EPA releases Asbestos Study results.

December 1974 – U.S. Senate passes S 3922, Amendment of the Coastal Zone Management Act of 1972, including Section 2: "In any action requesting equitable relief, under any Act administered by the Administrator of the Environmental Protection Agency or instituted at the request of such Administrator, where a risk to public health is alleged and established, the failure by the party requesting such relief to prove that demonstrable harm to health now exists or will result, shall not, in and of itself, constitute a permissable basis to deny such relief. . ." A similar amendment was defeated in the U.S. House of Representatives.

Sources: Minnesota Pollution Control Agency; Superior Polluter, Save Lake Superior Association and Northern Environmental Pollution Council, Duluth, Minnesota, October 1972; *Environment Midwest May 1974;* and Stephan Burrell (for Minnesota Pollution Control Agency), "Amphiboles in Taconite From The Peter Mitchell Mine," Reserve Mining Company, Babbitt, Minnesota, University of Wisconsin, June 1973. Congressional Record-Senate, December 18, 1974.

APPENDIX 3

SELECTED PROCEEDINGS OF THE I.J.C. PUBLIC HEARING, DULUTH, MINNESOTA, DECEMBER 7, 1972

The first reported public reference to potential human health effects, specifically the linkage to cancer, was made by Mrs. Arlene Lehto of the Lake Superior Association in December, 1972, at the International Joint Commission's Duluth public hearing on references of water pollution of the Upper Lakes and the Great Lakes System from land use activities.

MRS. LEHTO'S PRESENTATION

THE CHAIRMAN: Next may I call on Miss, or Mrs. Arlene Lehto of this same Lake Superior Association.

MRS. LEHTO: I thank you very much for letting me appear this morning. I'll try to be fairly brief with my statement.

My purpose is to respond to the two questions that have already been asked, on the 67,000 long tons, which in reality is approximately 69,000 tons. We have taken that to be a close estimate of the production at their normal levels, and this is the approximation of the daily discharge into Lake Superior. On the findings of solid particles of matter that closely resembled and were identified by some as taconite tailings in toilet tanks in Duluth, Minnesota, as I live here also, Duluth does not filter its water as it takes it from the lake, it takes it directly, and only treats it with chlorine and fluoride and we drink it, we consume it. The particulate matter that is brought in is not filtered out, it is consumed by us, and it can very easily be found in all of the water supplies in Duluth.

The individual that I know that has identified this particulate matter as being taconite tailings, was an employee biologist at the National Water Quality Lab here in Duluth. I don't know whether I'm at liberty to give his name or not, so I shall not.

I am President of the Save Lake Superior Association based here in Duluth, Minnesota. We have branches in Wisconsin, Michigan and the Twin Cities, and we did at one time have a working agreement sort of relationship with the members at Sault Ste. Marie, Michigan, and Canada. The statement that I would like to read to you this morning is on behalf of our Board of Directors of Save Lake Superior Association, who number approximately 1,000 at this time.

Lake Superior represents one of the most valuable resources on the North American Continent, part of a system which contains approximately one-fifth of the available fresh water on the face of the earth. The history of the International Joint Commission, especially the reference of Lake Erie in 1917, can show us that past efforts have been ineffective in preventing the pollution of lakes Huron, Michigan, Ontario and Erie.

Unless preventive steps are taken immediately, Lake Superior will suffer the same fate, ending forever the possibility of cleansing the Great Lake System with clean water from Lake Superior. Especially now as our Governments are studying the possibility of an extended shipping season, we are gravely concerned about the sources of pollution on Lake Superior and the uniformity of laws and regulations which could provide for abatement of that pollution on an equal basis, while creating no economic disparities. The Save Lake Superior Association is particularly concerned about the treatment of commercial and recreational shipboard wastes, most of which have been incinerated or discharged directly into the Lake in the past. Treatment of dockside may

create an economic disparity in user fee and port time lost, and this activity could rightfully or should rightfully be uniformly available at all ports throughout the Great Lakes, both the United States and Canadian.

In like manner, there should be a uniform mandatory compliance with pollution abatement laws for municipalities and industries which discharge their wastes directly into Lake Superior or any other Great Lake.

The United States and Canadian Governments as well as private citizens of both countries have invested heavily in the development and promotion of such attractions and facilities as the Circle Route around Lake Superior which is utilized by both Americans and Canadians on holiday and as a service route. Our lake is world renowned for its purity and clarity. This asset, singular perhaps, as it gets a little cold for swimming and that sort of activity, is being violated in an appalling manner by one industry. An industry while through a combination of political stringpulling, economic fear tactics, legal manoeuvering and sheer gall, had circumvented justice and continues daily to pour a mountain of filth into this international body of water.

The truly admirable efforts on the part of both countries and their citizenry in such developments as the Circle Route, is being betrayed by this one industrial polluter which continues to evade any abatement schedule and daily violates the crystal waters of Lake Superior. This largest industrial user takes up to 700 million gallons of water a day from the lake and discharges it back into the lake with a waste load of nearly 69,000 tons of taconite tailings. Scientists estimate that approximately 20 tons of this daily tailings discharge dissolves into Lake Superior. Whatever, enough goes into permanent suspension and begins a vicious route of circulation through our lake causing a nuisance discolouration which for longer and longer and larger periods becomes an ugly and ever growing scar on the waters of Lake Superior. And whether this is the only violation of these waters we can't be certain yet.

The Japanese have only recently discovered that the asbestos used in the grinding process for their rice may be a cancer-producing agent. The character of taconite tailings also includes the same fibrous amphibole. To our knowledge, no one has even suspected that this might be a cancer-producing agent. And because historically the burden of proof has rested not with the polluter, but with the victim, our daily ingestion of polluted water will continue – perhaps until too late.

But there are alternatives. The main one of these alternatives being sought here and in court by the Save Lake Superior Association is on-land disposal for this discharge by Reserve Mining Company. And not necessarily on-land in the vicinity of the present plant, but perhaps even on-land at the actual mine site. True, they would again be utilizing waters which are international in nature, but by a new commitment to their investment they could also utilize more advanced methods of processing which would recycle their water and no longer jeopardize the health and welfare of citizens of both United States and Canada as their present discharge does in its integration with the Great Lakes.

Again, we wish to stress our concern for the establishment of uniform availability of treatment for shipboard waste at all Great Lake ports and for the abatement of all gross pollution in the Great Lakes, particularly that which violates our waters of Lake Superior.

Thank you.

I would also like to enter into the record as though read, hopefully, this copy of the *Superior Polluter* which has been co-published jointly with the Northern Environmental Council. A book which documents in 196 approximate pages the full story of the Reserve Mining Company saga struggle since 1947. Hopefully this will give you the factual data. It was compiled by three university law students who are now full attorneys in the United States.

DISCUSSION

THE CHAIRMAN: Thank you very much, Mrs. Lehto. I think there may be some questions from members of the Commission. I would ask a perfectly simple question. If all of what you say is true, why has the City of Duluth not done something about this?

MRS. LEHTO: I believe the economic weapon that has been wielded, directly affects them. As the Duluth area Chamber of Commerce has stated, they fear that they will lose more jobs for the region, and their sales will be going down drastically if they lost some of this population at Silver Bay which uses Duluth as a service area. They have almost no stores of their own up there. They do almost all of their shopping in the Duluth area.

THE CHAIRMAN: Have the Reserve Mining people, Mrs. Lehto, indicated why they could not use land disposal methods for this?

MRS. LEHTO: During the Court proceedings in Lake County District Court they had many and varied reasons and most of them boiled down to economics.

THE CHAIRMAN: Thank you very much. Are there any questions? Yes, Mr. Robichaud?

COMMISSIONER ROBICHAUD: Yes, again a very simple one. What is the background of the Association that you represent? Save the Lake - - -

MRS. LEHTO: Save Lake Superior Association.

COMMISSIONER ROBICHAUD: Could you give us a little of the background of this organization?

MRS. LEHTO: Yes, it was formed by a nucleus of approximately 14 or 15 people on the north shore of Lake Superior on February 22, 1969. The idea was germinated by an individual who came to my family, my parents, and asked what they thought should be done, what could the few handfuls of residents that live on the shore do about this fantastic practice of using the lake as a dumping ground, and my parents referred them to other existing organizations. These other existing organizations had very little voice themselves. When I heard about it, I said that I think the only way we can do anything is to organize our own group, and it was founded on February 22, 1969; and we immediately began calling everyone we had ever heard of or talked to that was concerned with the same problem. We formed this small nucleus, and from this we heard of other people who also thought something should be done; and we went from there to probably incorporate more people from Ashland, Wisconsin who were concerned with the Dupont effluent. It wasn't just the one situation that triggered it off, perhaps it was at the very beginning with the first five or six people, but then they decided that there were so many pollution problems on Lake Superior. Personally, it was my own experience, on seeing what had happened to this lovely body of water, as I was absent from this area for approximately 11 years, and I came back in May of 1968 after an approximate 11 year absence and could not believe the amount of degradation that had already taken place.

The clarity of the water from the cliffs where I used to play as a child was so impaired that I just couldn't believe that could happen to something so beautiful, and something that had such purity and such impact on my life when I was growing up. It had been an inspiration to me and I just thought that this should not happen in the United States of America.

I had no background in conservation myself, and only one person out of the initial group did, he was a forester. It was a grass roots movement, and from there we incorporated assistance from The Citizens To Save Lake Superior, Save The Superior Shoreline in Marquette, Michigan because we heard their interests were alike. This is sort of the background of the organization.

THE CHAIRMAN: You have, I take it, Canadian members too?

MRS. LEHTO: Yes, very few unfortunately. I have been to Thunder Bay and spoke to the University Confederation of Colleges, I believe it was, at their conference approximately two years ago in the fall. People were sort of interested, but they felt their problems there were so vast that they could not become too much concerned with ours. We have some who are retaining memberships, but unfortunately are not very active.

THE CHAIRMAN: Thank you, Mrs. Lehto. Are there any other questions? Commissioner Beaupré?

COMMISSIONER BEAUPRÉ: You were mentioning that about 20% of the total tailings were being dissolved?

COMMISSIONER WEBER: Twenty tons.

MRS. LEHTO: No, 20 tons.

COMMISSIONER BEAUPRÉ: Do you know exactly what – was there any test made of exactly what this was?

MRS. LEHTO: I don't recall personally because I don't have the scientific background that I could, you know, tag that immediately in its proper relationship, but this was part of the testimony that was not refuted at the Lake County District Court trial and Two Harbours. I don't recall at the moment, I'm sorry, which scientist gave that particular –

COMMISSIONER BEAUPRÉ: If it is dissolved in the lake, it may not be that important.

MRS. LEHTO: It is dissolved daily. It has to be a tremendous impact on the lake. Perhaps it isn't the amount that is dissolved, but that amount that stays in permanent suspension and may never dissolve, or you know, be an irritant.

COMMISSIONER BEAUPRÉ: We were told that 40% of the total tailings were in a colloid state and would remain in suspension for quite awhile, which is more important? That is most probably responsible for the lack of purity and clarity of the water that you have noticed.

MRS. LEHTO: Our concern I believe – the Board of Directors of Save Lake Superior Association has discussed this in some depth – and I believe the concern with the dissolved portion, is the concern that that portion which acts as a carrier agent and could possibly act as a carrier agent for bacteria and such, and would enter a water supply, particularly that like Duluth, which is not filtered.

COMMISSIONER BEAUPRÉ: Thank you.

THE CHAIRMAN: Thank you. Commissioner Ross?

COMMISSIONER ROSS: Mrs. Lehto, as Chairman Herter indicated we are concerned not only with pollution of Lake Superior and Lake Huron, we are also concerned about the problem of agricultural and urban land run-off. Do you know whether there is any group in this area who has investigated this problem to any extent; and to what extent is your association concerned with this as a problem, if it is?

MRS. LEHTO: We definitely feel it is a problem. We have been concerned and perhaps involved on a far greater scale with the Great Lakes Basin Commission. I served myself on the task force for two years, and our involvement has been mostly through input into their studies. Hopefully into upgrading the inadequacies, fantastic inadequacies of the U.S. Army Corps of Engineers National Shoreline Study, and having some influence hopefully on getting other groups to study the land use and make an inventory of it. We feel this is extremely important. It is our understanding that the Minnesota Public Interest Research Group, locally, or in the State of Minnesota, is undertaking such a study. I don't know to what extent they will be successful in completing it in time for input into their shoreline survey, updating by the Army Corps of Engineers. The Great Lakes Basin Commission is supposedly compiling data on land use and we feel that that also is not adequate for the north shore of Lake Superior and the Canadian portion. We feel that because it doesn't include the Canadian portion, it doesn't show a true picture of what is happening region-wise and basin-wise on land use, and this is perhaps where the scope of the I.J.C. should take precedence.

COMMISSIONER ROSS: Do you know whether the Minnesota Public Interest Group is going to appear today?

MRS. LEHTO: They are supposed to, to the best of my knowledge, yes.

THE CHAIRMAN: Are there any other questions, Mr. Weber?

We certainly appreciate, and will be glad to note for the record, the book which you have referred to.

MRS. LEHTO: Thank you.

APPENDIX 4
CURRENT INVESTIGATIONS

LAKE SUPERIOR ASBESTOS STUDY

EPA, Region V, is sponsoring the Lake Superior Asbestos Study to obtain information on the ambient air quality in the areas affected by taconite operations and to determine the concentration of asbestiform amphibole fibres in the municipal water intakes using Lake Superior as a water source, in major tributaries to Lake Superior, and in the open waters of Lake Superior. In addition, the study will provide background data to support estimates of future use of Lake Superior water for human consumption and to measure the environmental effects should the Reserve Mining Company be terminated.

Field sample collection in support of the lake sampling, potable water intake and tributary sampling and meteorological data acquisition programs have been completed. Ambient air monitoring was initiated in November, 1973. Laboratory analyses of collected samples have been initiated.

Lake Sampling Program

The objectives of the Lake Sampling Program are to monitor asbestiform amphibole fibre concentrations in Lake Superior as they may be affected by discharge of taconite tailings at Silver Bay and resuspension of sediments by storms; to provide background data to support estimates of concentrations of asbestiform amphibole fibres in the lake if the discharge of taconite tailings is abated; to provide data to relate asbestiform amphibole fibre concentrations found in local potable water intakes to concentrations found in Lake Superior; and to determine if the bulk of the asbestiform amphibole fibres settle with the tailings or are carried to open water. The Lake Sampling Program includes collecting water samples at designated stations and collecting samples of the bottom muds under the water columns sampled. Table 4-1 lists the Lake Sampling Program sampling stations and the number of water and sediment samples collected at each. Figure 4-1 shows the Lake Superior sampling station locations.

The water samples collected from Lake Superior are being analyzed for total suspended solids and mineralogical identification by x-ray diffraction where sufficient sediment is available. The samples are also being analyzed for asbestiform amphibole fibre content including mass concentration, fibre count, size distribution and fibre identification. Additional information being collected in the field includes sample temperature, a temperature profile within the water column being sampled, a transmissometer profile, secchi disc reading, and weather conditions. Bottom sediment samples will be analyzed for mineralogical content by x-ray diffraction and for asbestiform amphibole fibres including mass concentration, fibre count, size distribution, and fibre identification.

Potable Water Intake and Tributary Sampling Program

The purpose of this program is to determine the existing amounts and characteristics of asbestiform amphibole fibres in potable water intakes using Lake Superior as their source; to monitor the asbestiform amphibole fibre concentrations in potable water intakes as they may be affected by the termination of the taconite tailings discharge at Silver Bay and by resuspension of sediments by storms; and to determine the amounts, if any, of asbestiform amphibole fibres entering Lake Superior from major tributaries. Table 4-2 lists the potable water intake and tributary sampling stations. Figure 4-2 in a location map showing sampling locations.

TABLE 4-1

LAKE SUPERIOR ASBESTOS STUDY[36]
LAKE SAMPLING PROGRAM

Sampling Stations

Station No.	Description	Depth Contour (feet)	Number of Samples	
			Water	Sediment 1/
LS – 1	Near: Palisade Head	100	12	1
LS – 2	Palisade Head	200	12	1
LS – 3	Palisade Head	300	12	1
LS – 4	Palisade Head	600	12	1
LS – 5	Beaver Bay	100	12	1
LS – 6	Beaver Bay	200	12	1
LS – 7	Beaver Bay	300	12	1
LS – 8	Beaver Bay	600	13	1
LS – 9	Two Harbors	100	27	1
LS –10	Two Harbors	200	12	1
LS – 11	Two Harbors	300	57	1
LS – 12	Two Harbors	600	12	1
LS – 13	Sand Island	100	12	1
LS – 14	Sand Island	200	12	1
LS – 15	Sand Island	300	12	1
LS – 16	Sand Island	600	13	1
LS – 17	French River	100	12	1
LS – 18	French River	200	12	1
LS – 19	French River	300	12	1
LS – 20	Reserve Mining	20-80	5	1
LS – 21	Duluth	100	12	1
LS – 22	Grand Marais	100	12	1
LS – 23	Grand Marais	200	12	1
LS – 24	Grand Marais	300	12	1
LS – 25	Grand Marais	600	12	1

1/ Each sample consists of 2 – cores and 1 – composite dredge portion.

NOTE: All stations were sampled at the surface (3m), mid-depth, or sub-surface turbid layer and near the bottom (Bottom-6m) except at station LS–20, which was sampled in the visually turbid area near the delta. Station LS–9 was sampled daily during the first cruise, while LS–11 was selected for daily sampling during the remaining three cruises.

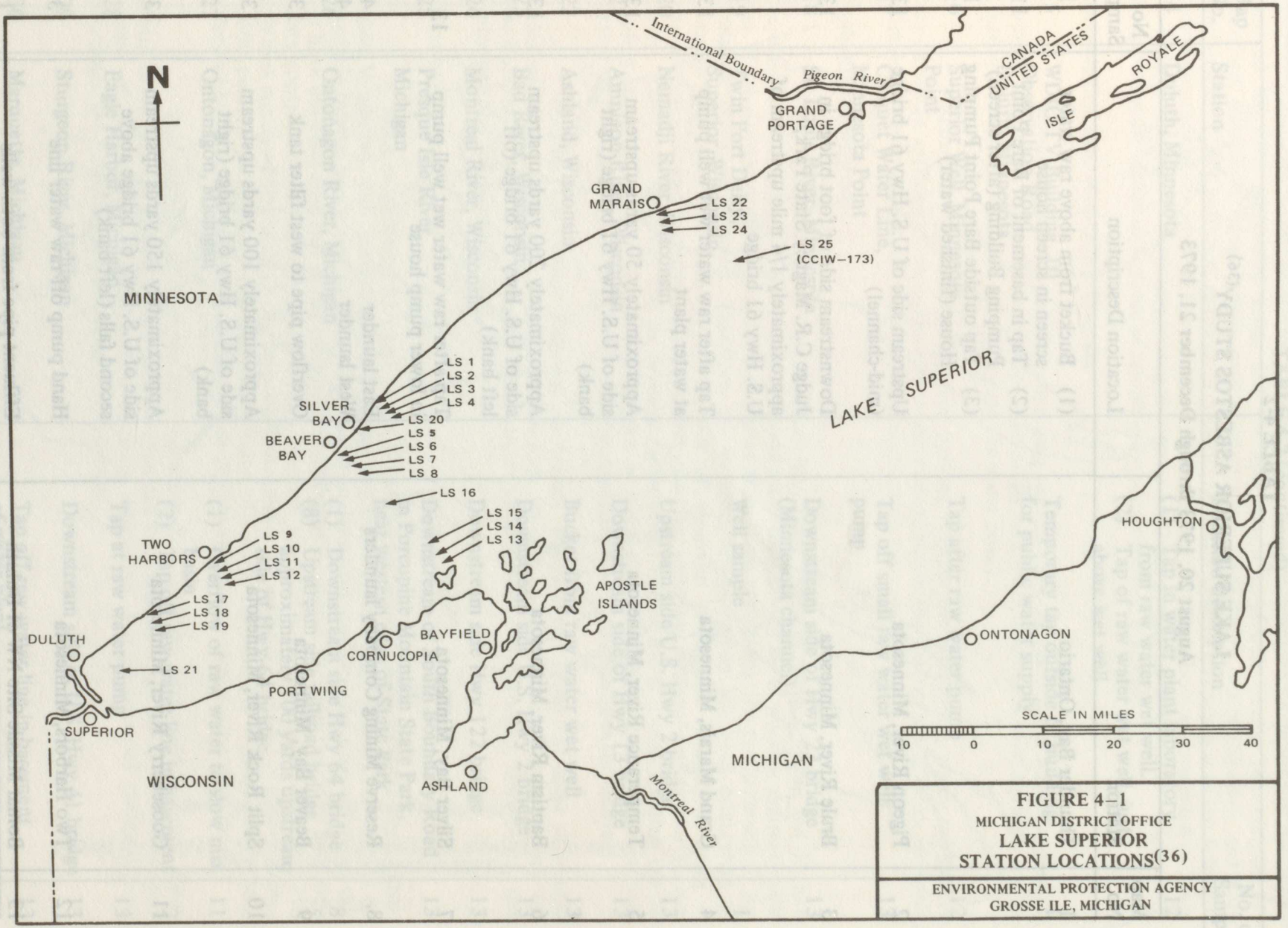


FIGURE 4–1
MICHIGAN DISTRICT OFFICE
LAKE SUPERIOR
STATION LOCATIONS(36)

ENVIRONMENTAL PROTECTION AGENCY
GROSSE ILE, MICHIGAN

TABLE 4-2

LAKE SUPERIOR ASBESTOS STUDY[36]

August 20, 1973 through December 21, 1973

Map No.	Station	Location Description	No. of Samples
1	Thunder Bay, Ontario	(1) Bucket from above raw water screen in screen house	1
		(2) Tap in basement of Bare Point Pumping Building (after screen)	11
		(3) Tap outside Bare Point Pumping House (finished water)	1
2	Pigeon River, Minnesota	Upstream side of U.S. Hwy 61 bridge (mid-channel)	13
3	Brule River, Minnesota	Downstream side of foot bridge in Judge C.R. Magney State Park, approximately 1/4 mile upstream of U.S. Hwy 61 bridge	13
4	Grand Marais, Minnesota	Tap after raw water wet well pump at water plant	13
5	Temperance River, Minnesota	Approximately 50 yards upstream side of U.S. Hwy 61 bridge (right bank)	13
6	Baptism River, Minnesota	Approximately 200 yards upstream side of U.S. Hwy 61 bridge (off left bank)	13
7	Silver Bay, Minnesota	Tap after raw water wet well pump in lower pump house	13
8.	Reserve Mining Company launders	East launder	4
		West launder	4
9	Beaver Bay, Minnesota	Overflow pipe to west filter tank	13
10	Split Rock River, Minnesota	Approximately 100 yards upstream side of U.S. Hwy 61 bridge (right bank)	13
11	Gooseberry River, Minnesota	Approximately 150 yards upstream side of U.S. Hwy 61 bridge above second falls (left bank)	13
12	Two Harbors, Minnesota	Hand pump off raw water line	13
13	Bomar Missile Site NW of Duluth	Effluent pipe from both wells	1

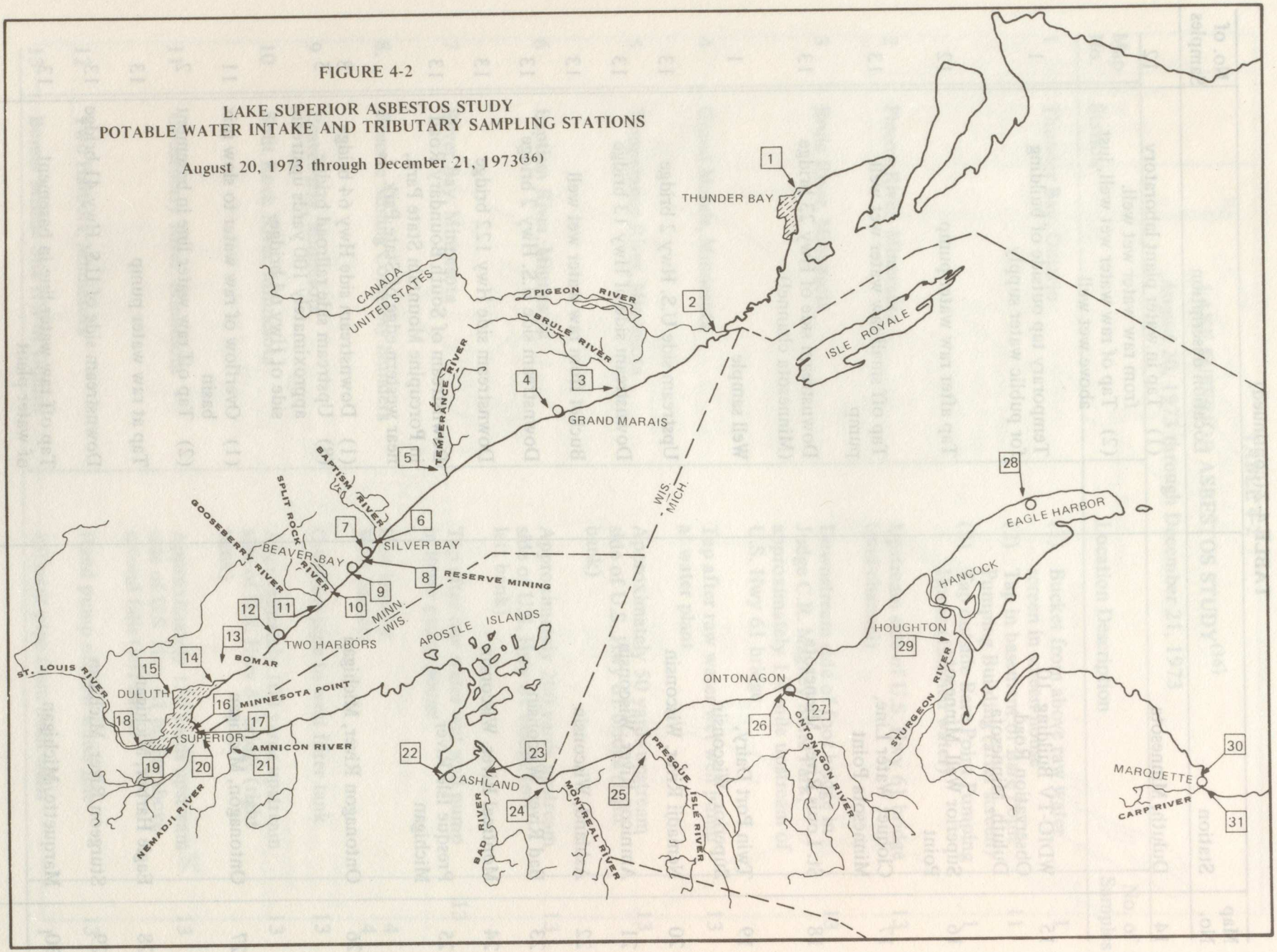
TABLE 4-2 (continued)

Map No.	Station	Location description	No. of Samples
14	Duluth, Minnesota	(1) Tap in water plant laboratory from raw water wet well. (2) Tap of raw water wet well, just above wet well	12
15	WDIO-TV Building, 10 Observation Road, Duluth, Minnesota	Temporary tap outside of building for public water supply	1
16	Superior Well, Minnesota Point	Tap after raw water pump	12
17	Cloquet Water Line, Minnesota Point	Tap off small raw water wet well pump	13
18	St. Louis River, Minnesota	Downstream side of Hwy 23 bridge (Minnesota channel)	13
19	Twin Port Dairy, Superior, Wisconsin	Well sample	1
20	Nemadji River, Wisconsin	Upstream side U.S. Hwy 2 bridge	13
21	Amnicon River, Wisconsin	Downstream side of Hwy 13 bridge	13
22	Ashland, Wisconsin	Bucket from raw water wet well	13
23	Bad River, Wisconsin	Downstream side U.S. Hwy 2 bridge	13
24	Montreal River, Wisconsin	Downstream side Hwy 122 bridge	13
25	Presque Isle River, Michigan	Downstream of South Boundary Road in Porcupine Mountain State Park, near western edge of State Park	13
26	Ontonagon River, Michigan	(1) Downstream side Hwy 64 bridge (8) Upstream side railroad bridge approximately 100 yards upstream side of Hwy 64 bridge	8 5
27	Ontonagon, Michigan	(1) Overflow of raw water to slow mix basin (2) Tap off raw water line in basement	11 2
28	Eagle Harbor, Michigan	Tap at raw water pump	13
29	Sturgeon River, Michigan	Downstream side of U.S. Hwy 41 bridge	13
30	Marquette, Michigan	Tap off raw water line in basement of water plant	13
31	Carp River, Michigan	75 yards upstream side of U.S. Hwy 41 bridge (right bank)	12

FIGURE 4-2

LAKE SUPERIOR ASBESTOS STUDY
POTABLE WATER INTAKE AND TRIBUTARY SAMPLING STATIONS

August 20, 1973 through December 21, 1973[36]



Samples taken from the potable water lines and from the tributaries are being examined for total suspended solids and for asbestiform amphibole fibres. The analyses for asbestiform amphibole fibres include mass concentration, fibre count, size distribution, and fibre identification. Where sufficient sediment is present, the mineralogical composition of the sediment is being determined by x-ray diffraction. The 1973 results of these analyses are presented in Table 4-3. Results of electron microscopy analysis during 1973 are presented in Table 4-4. Figures 4-3 through 4-5 show results of analyses of sampling for concentrations and mass.

Meteorological Data Acquisition Program

Meteorological data are acquired as a parallel study to the Potable Water Intake and Tributary Sampling Program. Weather conditions affect lake water movement characteristics which, in turn, have an affect on water drawn through the water intake.

Table 4-5 lists the meteorological stations, existing and established, which are used in order to obtain sufficient data to describe weather conditions in the western arm of Lake Superior. Figure 4-6 is a map locating the meteorological stations.

Air Monitoring Program

The communities of Duluth, Silver Bay, Hoyt Lakes, Babbitt, Virginia and Eveleth have taconite mining, processing or loading operations in close proximity to workers and residential areas. If asbestiform amphibole fibres are emitted from these operations, the public health of the population could be affected. Therefore, an air monitoring program has been established to determine not only the presence or absence of air-borne asbestiform amphibole fibres in communities near the taconite operations, but also the exposure level to populations to this vicinity. Table 4-6 identifies the air monitoring network. Figure 4-7 is a map locating the 10 sampling stations. The Air Monitoring Program is designed to continue for one year and was initiated on November 12, 1973. Twenty-four hour samples are collected once every 6 days.

Region V's Central Regional Laboratory analyzes the filters for total suspended particulate matter and iron. The filters are then sent to an outside contract laboratory for asbestiform amphibole fibre analyses. The analyses include mass concentration, fibre count, size distribution and fibre identification.

Laboratory Program

Since no approved EPA method for the analyses of asbestiform amphibole fibres exists, Region V worked with the Office of Research and Development, Headquarters, to develop an acceptable interim procedure. Interim procedures were developed; however, these procedures at this date have not been classified as an "Interim EPA Approved Procedure" pending results of analytical quality control data. Each contract laboratory has been provided with five standard solutions. The analytical results of the analyses of these standard solutions must be within plus or minus a factor of 300 percent the mean for a standard solution. To date, the standard solutions have been performed by all but one contract laboratory and all data have been within the specified limits.

The contract laboratories have been asked to perform fibre identification, group identification, size distribution, mass concentration and fibre counts. In addition, the mineralogical content of the solids will be identified by x-ray diffraction. For purposes of the laboratory procedures, the following definitions have been applied.

TABLE 4-3

Milligrams of Amphibole Particles Per Litre of Water by X-Ray Diffraction

1973

	8/22	8/29	9/6	9/14	9/19	9/26	10/3	10/10	10/17	10/24	10/31	11/14	11/28
1. Thunder Bay	<0.01	0.01	0.02	0.01	0.01	0.02		0.01	0.01	0.01	0.03	0.02	0.01
2. Grand Marais	0.01	<0.01		0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	<0.01
3. Silver Bay	0.01	0.01	<0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.27	0.05	0.02
4. Beaver Bay	0.32	0.27	4.03		0.28	0.29	0.05	0.12	0.12	0.30	1.78	0.37	0.12
5. Two Harbors	0.12	0.12	0.28	0.17	0.11	0.06	0.07	0.03	0.14	0.18	0.14	0.09	0.18
6. Duluth	0.12	0.08	0.10	0.06	0.15	0.10	0.06	0.02	0.06	0.04	0.06	0.08	0.26
7. Cloquet Water Line	0.02	0.05	0.16	0.01	0.08		0.10	0.03	0.06	0.03	0.03	0.14	0.02
8. Ashland	0.02	0.01	<0.02	0.02	<0.02	0.08	0.02	0.04	<0.02	<0.02	0.03	<0.01	<0.01
9 Ontonagon	0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
10. Eagle Harbor	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
11. Marquette	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
12. Superior (Wells)	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01		<0.05	<0.01	0.01	<0.01	<0.01

A value of zero was used for averaging purposes when the concentration was below the detection limit.

TABLE 4-4

Million Amphibole Asbestos Fibres Per Litre of Water as Measured by Electron Microscopy During 1973***

PWI	8/22	8/29	9/6	9/14	9/19	9/26	10/3	10/10	10/17	10/24	10/31	11/14	11/28
1. Thunder Bay	0							*0	*0.59	*2.1		*0	
2. Grand Marais**	*0	0				0.26	*0	*0	0.03	*0.12		*0	**
3. Silver Bay**		0.18		0	0.17	*0.14	*0	*0.46	*0.46	*0.08		*0.80	**
4. Beaver Bay**	*8.5	5.10		0.17			*1.2	*2.4	*6.6	*0.65		*59	**
5. Two Harbors**	*5.0	*4.4			1.1				*1.6	*3.0			**
6. Duluth**	*4.6					*2.2	*1.1			*1.9		*0.1	**
7. Cloquet Line	*1.8	*0.8				*0.8	*1.8	*0	*0.9	*1.1			
8. Ashland	*0		0	0.19		*0.25	*0.62	1.63	*0	*0		*0.06	
9. Ontonagon	0.70				0		*0.48	0	*0				
10. Eagle Harbor	0			0.17	0.18	*0.42	*0.08	0	*0	*0.16			
11. Marquette	0.19						*0	0.27	*0.17				
12. Superior, Wis. deep wells	*0	*0				*0.1	*0			*0.08		*0	

* Samples reported by McCrone Associates.

** Samples were also collected at these stations between dates of 4/24 and 5/6 in 1974. The data are not shown in the table but are included in the averages used later.

*** A fibre as a particle having a length of three times its width.

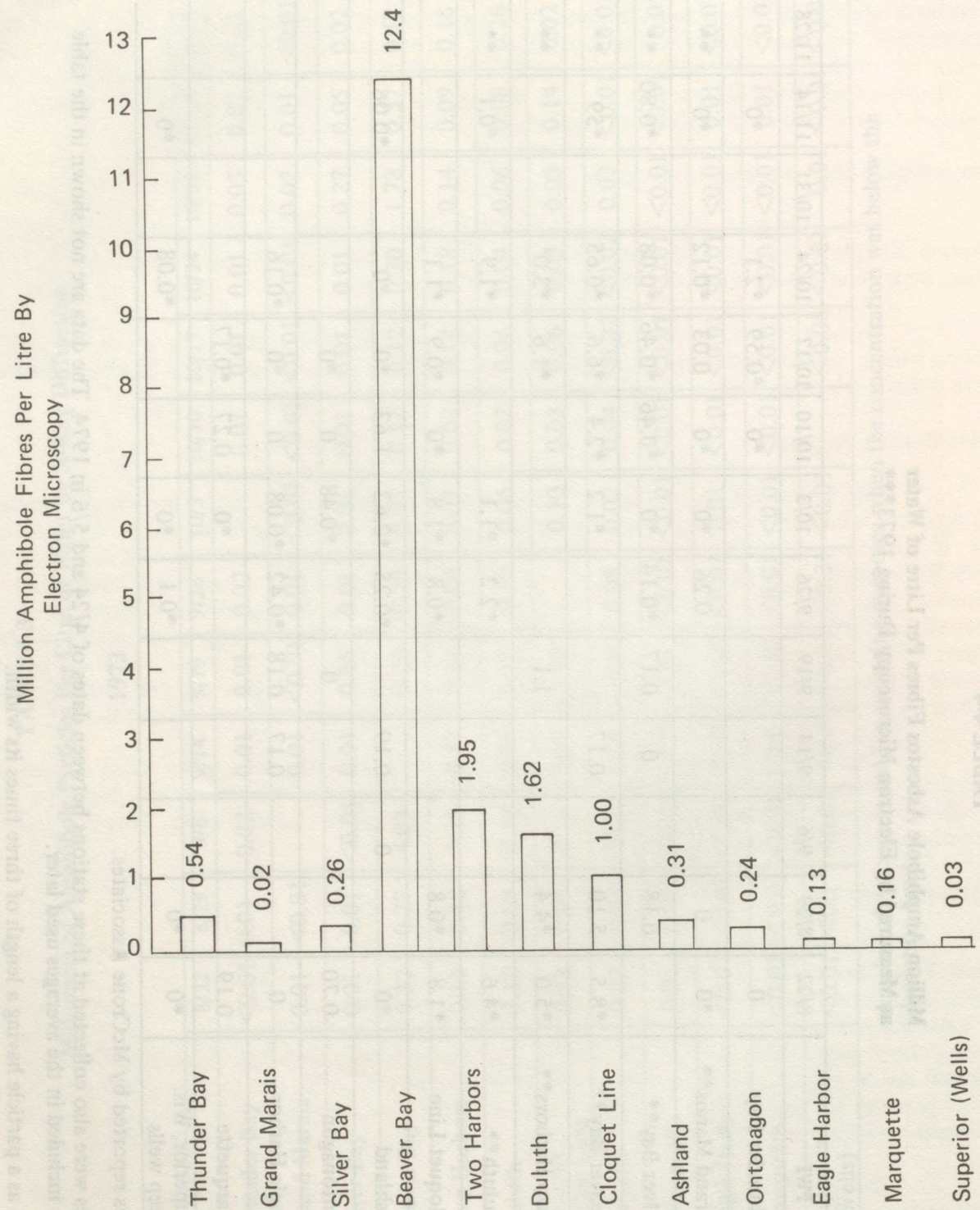


Figure 4-3 The values are average number concentrations of all samples analyzed prior to July 1, 1974. The contracting laboratories were required to identify each fibre they counted in the electron microscope.

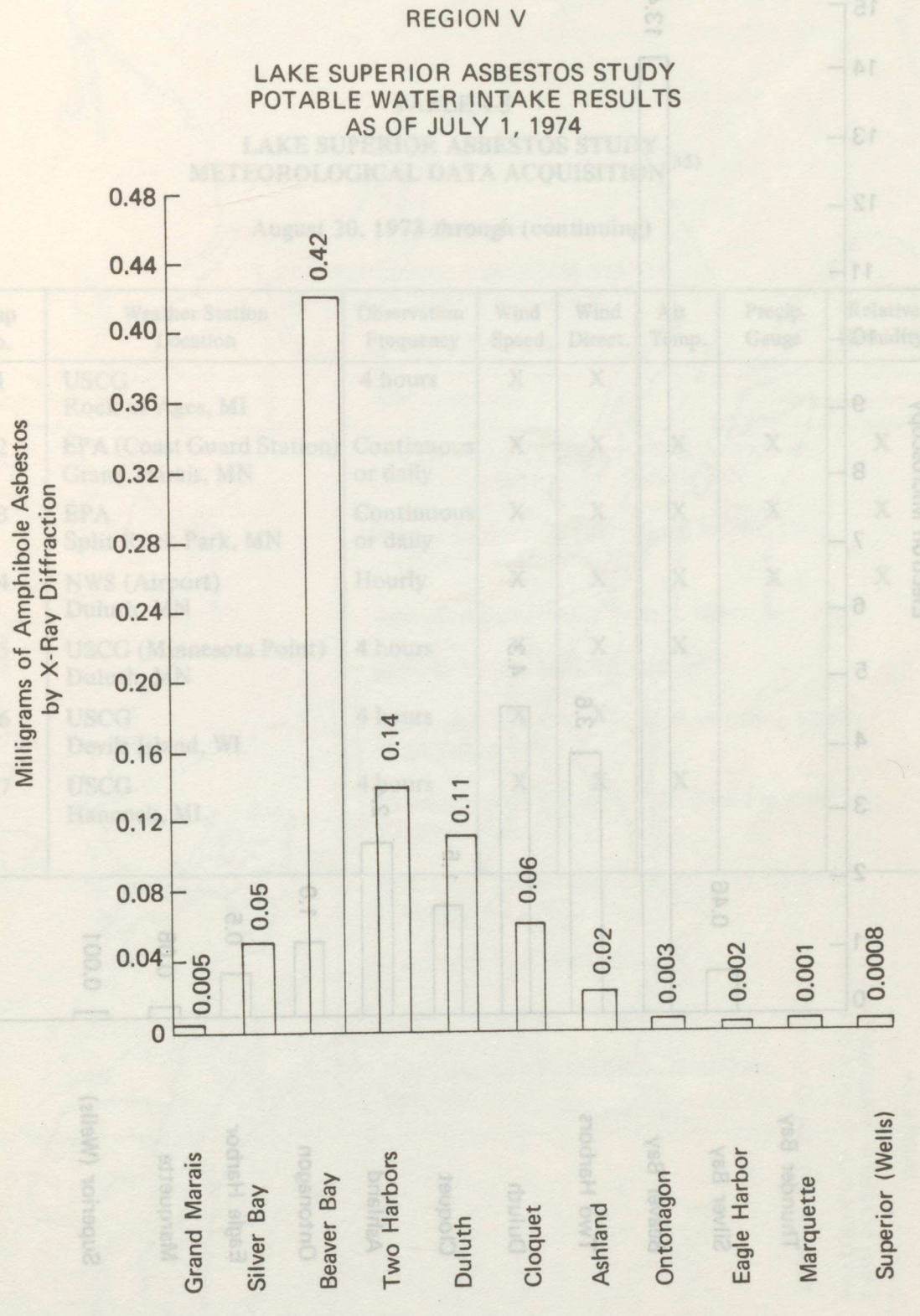


Figure 4-4 The concentrations are average values of all samples analyzed during the Study. The original data are shown in Table 4-3.

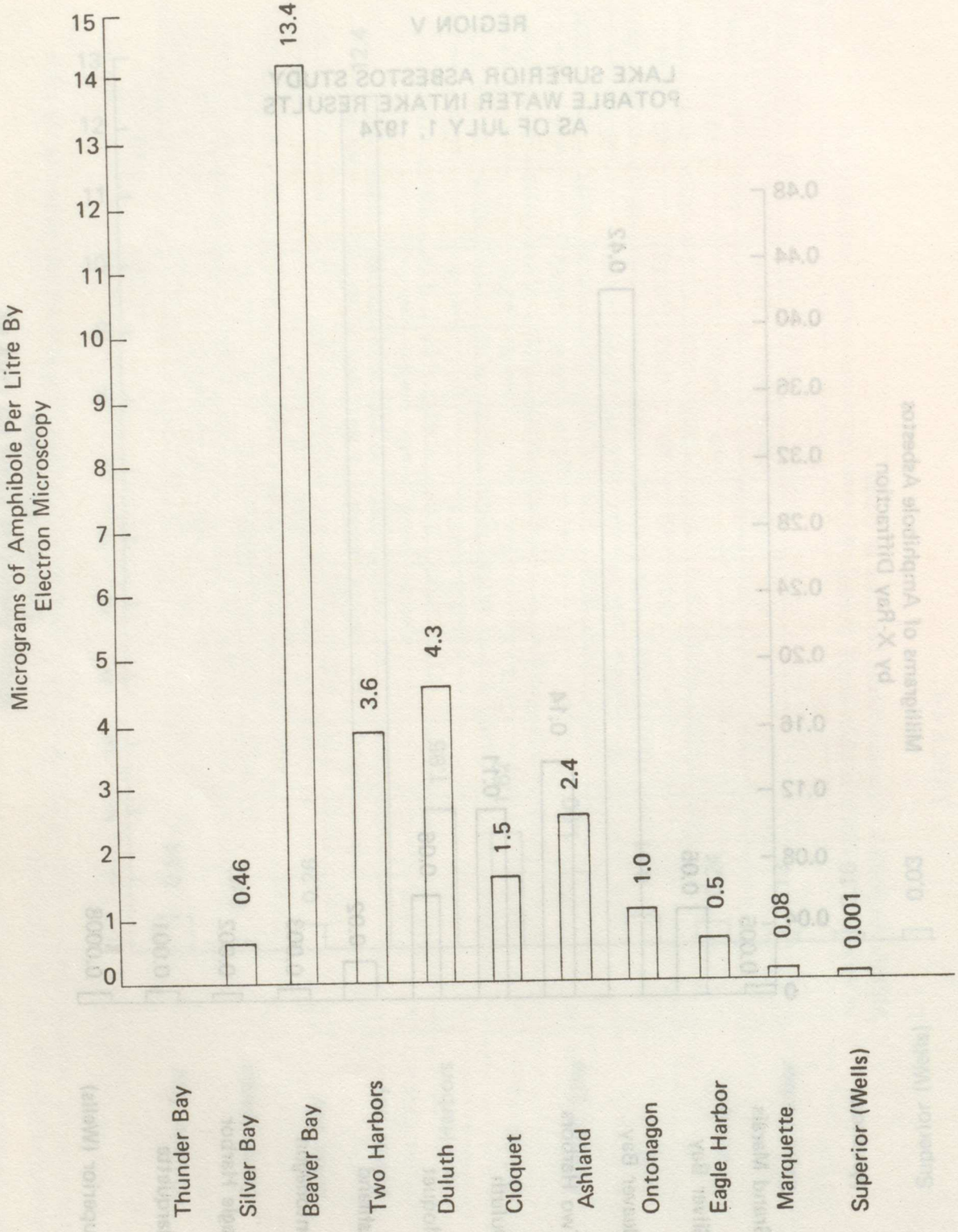


Figure 4-5

Values represent the calculated mass of the fibres described in Table 4-4 and Figure 4-3.

TABLE 4-5

LAKE SUPERIOR ASBESTOS STUDY METEOROLOGICAL DATA ACQUISITION[35]

August 20, 1973 through (continuing)

Map No.	Weather Station Location	Observation Frequency	Wind Speed	Wind Direct.	Air Temp.	Precip. Gauge	Relative Humidity
1	USCG Rock of Ages, MI	4 hours	X	X			
2	EPA (Coast Guard Station) Grand Marais, MN	Continuous or daily	X	X	X	X	X
3	EPA Split Rock Park, MN	Continuous or daily	X	X	X	X	X
4	NWS (Airport) Duluth, MN	Hourly	X	X	X	X	X
5	USCG (Minnesota Point) Duluth, MN	4 hours	X	X	X		
6	USCG Devils Island, WI	4 hours	X	X			
7	USCG Hancock, MI	4 hours	X	X	X		

FIGURE 4-6

LAKE SUPERIOR ASBESTOS STUDY
METEOROLOGICAL DATA STATIONS

August 20, 1973 through (continuing)

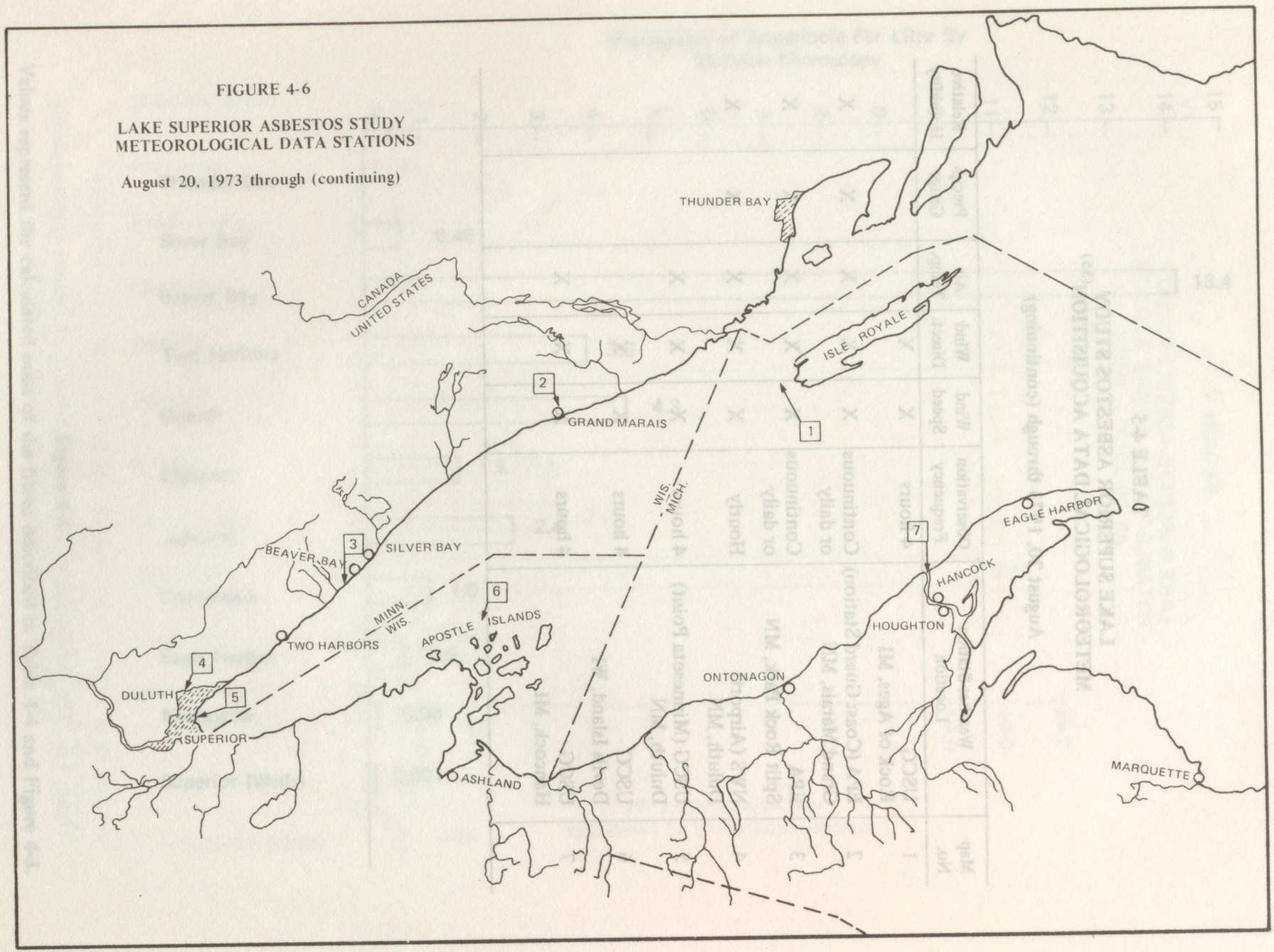


TABLE 4-6

LAKE SUPERIOR ASBESTOS STUDY AIR MONITORING PROGRAM[35]

Sampler Network

Site No.	Site Location
1	Sewage Pumping Station, 40th Avenue and Interstate Highway 35, Duluth, MN
2	Private Residence, 1300 Block North, 19th Avenue East, Duluth, MN
3	Compton Elementary School, Silver Bay, MN
4	Babbitt Village Hall, Babbitt, MN
5	Minnesota Power and Light Monitoring Trailer, Hoyt Lakes, MN
6	Hibbing Public Library, 2020 East 5th Avenue, Hibbing, MN
7	First National Bank of Cloquet, 715 Cloquet, Cloquet, MN
8	Pengilly School, Pengilly, MN
9	Virginia City Hall, Virginia, MN
10	Mountain Iron Post Office, Mountain Iron, MN

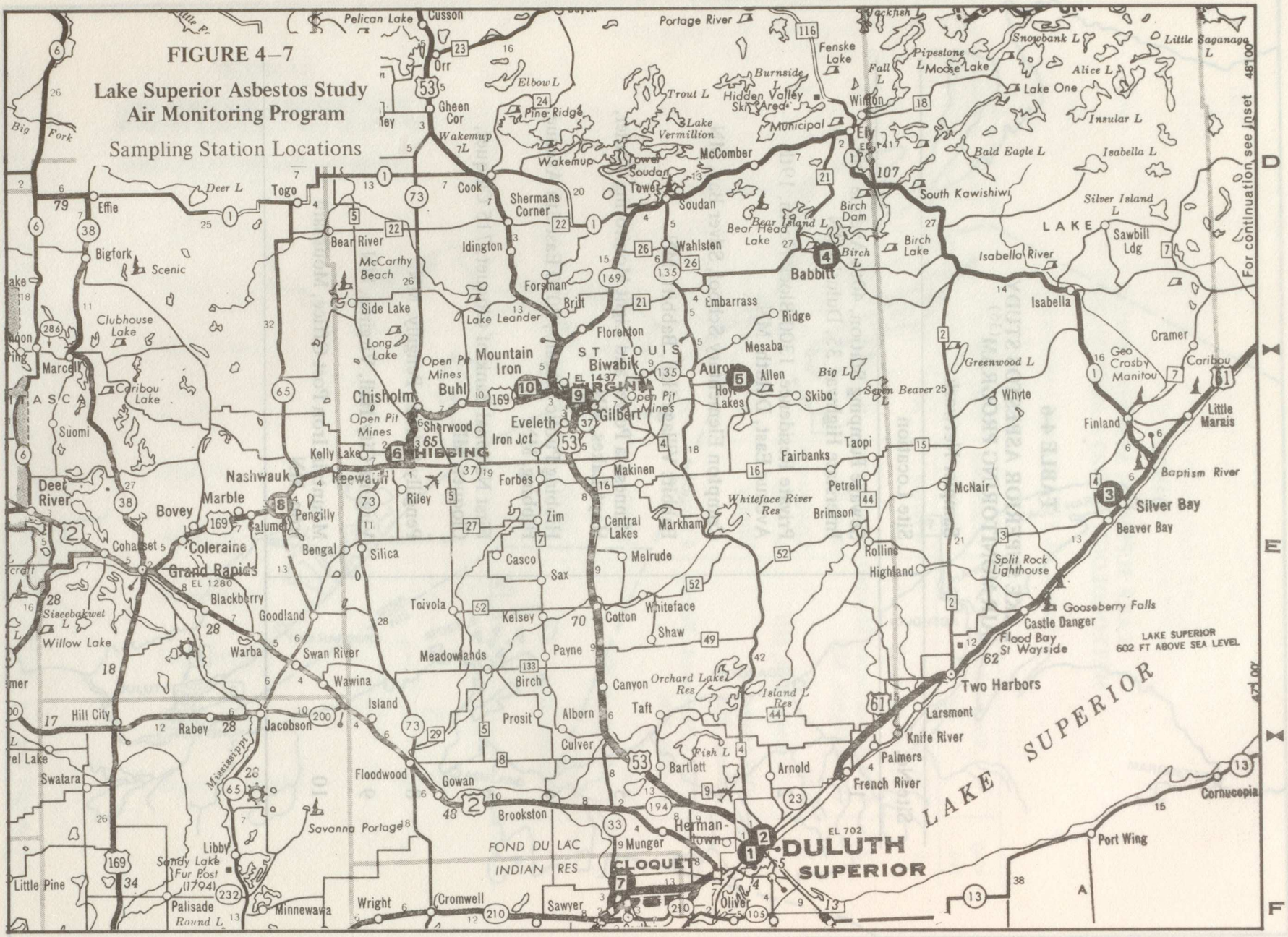


FIGURE 4–7
Lake Superior Asbestos Study
Air Monitoring Program
Sampling Station Locations
For continuation, see Inset 48100
LAKE SUPERIOR
602 FT ABOVE SEA LEVEL
DULUTH
SUPERIOR
HIBBING
CLOQUET
Grand Rapids
EL 1280
Virginia
EL 1437
Babbitt
Ely
EL 1417
Two Harbors
EL 702
Silver Bay
Beaver Bay
Chisholm
Open Pit Mines
Mountain Iron
Biwabik
Gilbert
Eveleth
Aurora
Hoyt Lakes
Keewatin
Nashwauk
Coleraine
Bovey
Marble
Deer River
Cohasset
Calumet
Pengilly
Marcell
Bigfork
Effie
Togo
Cook
Orr
Cusson
Pelican Lake
Big Fork
Scenic
Clubhouse Lake
Caribou Lake
Suomi
Bear River
McCarthy Beach
Side Lake
Long Lake
Lake Leander
Idington
Shermans Corner
Forsman
Britt
Florenton
Wahlsten
McComber
Soudan
Tower
Wakemup
Wakemup L
Elbow L
Pine Ridge
Trout L
Lake Vermillion
Hidden Valley Ski Area
Municipal
Burnside L
Fenske Lake
Fall L
Pipestone L
Moose Lake
Snowbank L
Little Saganaga L
Alice L
Lake One
Insular L
Bald Eagle L
Isabella L
South Kawishiwi
Silver Island L
LAKE
Sawbill Ldg
Isabella River
Isabella
Birch Dam
Bear Island L
Bear Head Lake
Birch L
Birch Lake
Embarrass
Ridge
Mesaba
Allen
Big L
Skibo
Seven Beaver L
Greenwood L
Whyte
Cramer
Geo Crosby Manitou
Caribou
Finland
Little Marais
Baptism River
McNair
Petrell
Brimson
Taopi
Fairbanks
Whiteface River Res
Makinen
Forbes
Iron Jct
Sherwood
Buhl
Riley
Zim
Central Lakes
Markham
Melrude
Casco
Sax
Silica
Bengal
Pengilly
Goodland
Blackberry
Warba
Swan River
Wawina
Meadowlands
Payne
Birch
Canyon
Orchard Lake Res
Island L Res
Taft
Alborn
Prosit
Culver
Bartlett
Fish L
Arnold
Palmers
French River
Larsmont
Knife River
Rollins
Highland
Split Rock Lighthouse
Gooseberry Falls
Castle Danger
Flood Bay St Wayside
Cornucopia
Port Wing
Rollins
Whiteface
Shaw
Cotton
Kelsey
Toivola
Island
Hill City
Rabey
Jacobson
Willow Lake
Siseebakwet L
Swatara
Floodwood
Gowan
Brookston
Savanna Portage
Libby
Sandy Lake Fur Post
Little Pine
Palisade
Round L
Minnewawa
Wright
Cromwell
Sawyer
Oliver
Munger
Herman-town
FOND DU LAC INDIAN RES
Mississippi
Lake Superior

1. Asbestiform amphibole fibre identification is to determine the presence of chrysotile, crocidolite, amosite, anthophyllite, tremolite and actinolite.

2. Group identification is to determine if a fibre is of the serpentine (chrysotile) or amphibole group.

3. Size distribution is the number of fibres in 0.1 μ steps over the range from 0.01 μ in length and width to the maximum fibre size.

4. Mass concentration is the weight of asbestiform amphibole fibres per unit of sample.

5. Fibre count is the number of fibres per unit volume of sample.

Additional EPA Studies

Through studying natural run-off from land with different geological features, mining and milling operations, as well as other industrial sources, public water supply intakes, as part of a national asbestos sampling program, EPA will attempt to determine the amounts and kinds of asbestos discharged to the environment. EPA also has studies to investigate asbestos cement pipe as a source of drinking water contamination. Further, a major animal feeding study has been initiated in co-operation with the Food and Drug Administration to help determine how fibres interact with the tissues of laboratory animals and if asbestos fibres can be absorbed in the intestinal tract of the animals. Air and water sampling of different types of asbestos handling operations will assist EPA to decide whether further regulatory actions are necessary.*

UPPER LAKES STUDY

Under Task Group B of the International Joint Commission's Upper Lakes Reference Group, an investigation is planned to measure concentrations of asbestos fibres in the Upper Lakes and develop background information.

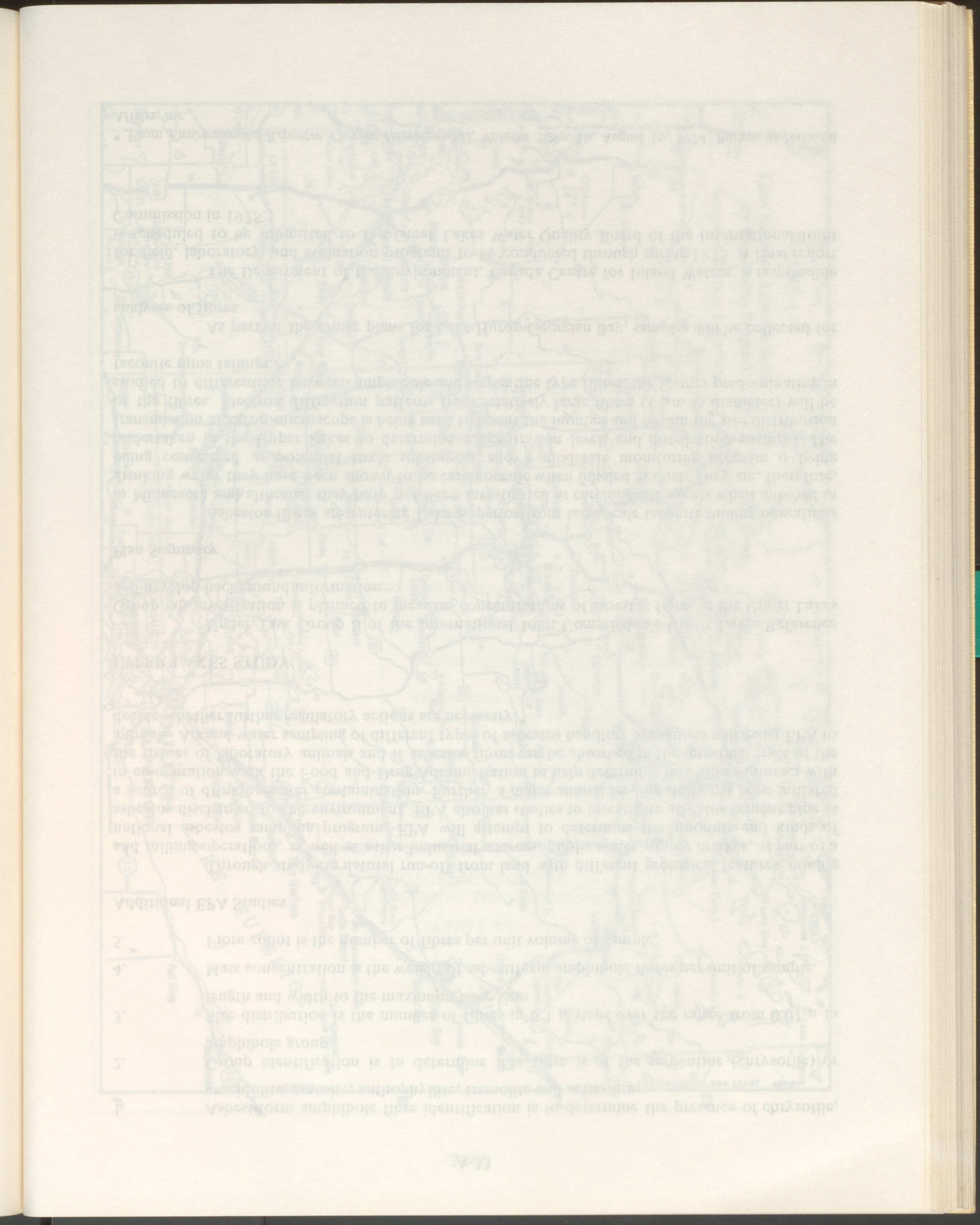
Plan Summary

Asbestos fibres are entering Lake Superior from large-scale taconite mining operations in Minnesota and although they have not been investigated as carcinogenic agents when imbibed in drinking water they have been shown to be carcinogenic when inhaled as dust. They are, therefore, being considered as potential toxic substances and a moderate monitoring program is being undertaken in the Upper Lakes to determine concentration levels and distribution patterns. The transmission electron microscope is being used to count the number and obtain the size distribution of the fibres. Electron diffraction patterns from relatively large fibres (1 μm in diameter) will be studied to differentiate between amphibole and serpentine type fibres; the former predominating in taconite mine tailings.

As part of the cruise plans for Lake Huron-Georgian Bay, samples will be collected for analyses of fibres.

The Department of the Environment, Canada Centre for Inland Waters, is responsible for field, laboratory, and evaluation programs to be conducted through spring 1975. A final report is scheduled to be submitted to the Great Lakes Water Quality Board of the International Joint Commission in 1975.

* From *Environmental Reporter, Current Developments,* Volume 5 No. 16, August 16, 1974, Bureau of National Affairs, Inc.



APPENDIX 5

RESERVE MINING V. U.S.

The decision of the Eighth Circuit Court of Appeals based on the Circuit Court's interpretation of technical evidence, is a preliminary review of Judge Miles Lord's findings and decisions. The U.S. EPA and the President's Council on Environmental Quality (CEQ) both asked the Justice Department to appeal the stay to the Supreme Court. CEQ Chairman, Russell Peterson, has stated that the appeals court "should not misread lack of knowledge about a potential hazard as proof that the hazard is slight or does not exist;" otherwise, "counting dead bodies. . ." is the only way the Government can prove its case using the Eighth Circuit's Standard. The Eighth Circuit Court of Appeals will hear Reserve Mining Company's appeal on the merits of Judge Lord's decision in 1975.

Judge Miles Lord's essential Findings of Fact and Conclusions of Law dated April 20, 1974 follow the Court of Appeals decision.

RESERVE MINING v. U.S.

U.S. Court of Appeals
Eighth Circuit

RESERVE MINING COMPANY, et al., v. UNITED STATES OF AMERICA, et al., No. 74-1291, June 4, 1974

WATER

Federal, state, and local regulation — Nuisance (§28.20)

Liability by industry — Mining (§32.55)

Court jurisdiction and procedure — Injunctions (§40.71)

Mining company's likelihood of prevailing on merits of its claim that Federal Government, in suit to enjoin company's discharge of taconite tailings into Lake Superior, failed to prove that discharge posed substantial danger to public health warrants 70-day stay of federal district court order that required immediate cessation of discharge, although stay is conditioned upon prompt action by company to abate discharge.

STATUTES

Federal — Federal Water Pollution Control Act (§95.021)

Construed.

Action by Federal Government, state, and environmental group plaintiffs to enjoin mining company's discharge of taconite tailings into Lake Superior. From order of U.S. District Court for the District of Minnesota enjoining discharge (6 ERC 1449), company applies for stay of injunction.

70-day stay of injunction granted.

Edward T. Fride, Duluth, Minn., and Wayne G. Johnson, Silver Bay, Minn., for appellants.

Edmund B. Clark, Department of Justice, Washington, D. C.; Byron E. Starns, chief deputy attorney general, St. Paul, Minn.; and Howard J. Vogel, Minneapolis, Minn., for appellees.

John Engberg, Minneapolis, for *amicus curiae*.

Full Text of Opinion

Before BRIGHT, ROSS and WEBSTER, Circuit Judges.

BRIGHT, Circuit Judge.

Reserve Mining Company is a jointly owned subsidiary of Armco Steel Corporation and Republic Steel Corporation which mines low-grade iron ore, called "taconite," near Babbitt, Minnesota. The taconite is shipped by rail to Reserve's "beneficiating" plant at Silver Bay, Minnesota, on the north shore of Lake Superior, where it is concentrated into "pellets" containing some 65 percent iron ore. The process involves crushing the taconite into fine granules, separating out the metallic iron with huge magnets, and flushing the residue into Lake Superior. Approximately 67,000 tons of this waste product, known as "tailings," are daily discharged into the lake.

The use of Lake Superior for this purpose was originally authorized by the State of Minnesota in 1947, and Reserve commenced operations in 1955. In granting this permit to Reserve, the State of Minnesota accepted Reserve's theory that the weight and velocity of the discharge would insure that the tailings would be deposited at a depth of approximately 900 feet in the "great trough" area of the lake, located offshore from Reserve's facility. The permit provides that:

> [T]ailings shall not be discharged * * * so as to result in any material adverse effects on fish life or public water supplies or in any other material unlawful pollution of the waters of the lake * * *.

This enforcement litigation was commenced after state and federal pollution control efforts dating from mid-1969 produced an unsuccessful series of administrative conferences and state court proceedings.[1] On February 2, 1972, the United States Government—joined eventually by the States of Minnesota, Wisconsin, and Michigan and by various environmental groups—filed a complaint alleging that Reserve's discharge of tailings into Lake Superior violated Section 13 of the 1899 Refuse Act (33 U.S.C. § 407), Section 10 of the Federal Water Pollution Control Act (33 U.S.C. § 1160), and the federal common law of public nuisance.

Until June 8, 1973, the case was essentially a water pollution abatement case, but on that date the focus of the controversy shifted to the public health impact of Reserve's discharge of asbestiform particles into the air and water. Hearings on a motion for preliminary injunction were consolidated with the trial on the merits, and on April 20, 1974, after 139 days of trial extending over a nine month period and after hearing more than 100 witnesses and examining over 1,600 exhibits, Judge Miles Lord of the United States District Court for the District of Minnesota entered an order closing Reserve's Silver Bay facility. In an abbreviated memorandum opinion, Judge Lord held that Reserve's water discharge violated federal water pollution laws and that its air emissions violated state air pollution regulations, and that both were common law nuisances. Most importantly to the question now before this court, Judge Lord concluded in Findings 9 and 10 of his opinion that:

> 9) The discharge into the air substantially endangers the health of the people of Silver Bay and surrounding communities as far away as the eastern shore of Wisconsin.
>
> 10) The discharge into the water substantially endangers the health of the people who procured their drinking water from the western arm of Lake Superior, including the communities of Silver Bay, Beaver Bay, Two Harbors, Cloquet, Duluth [Minnesota], and Superior, Wisconsin.

Defendants Reserve, Armco, and Republic[2] noticed their appeal to this court and moved for a stay of the district court's injunction pending the appeal. Judge Lord denied this request and Reserve applied to us for a stay.[3]

Upon consideration of Judge Lord's opinion of April 20, 1974, the written motion and supporting documents presented by Reserve, and after hearing the arguments of counsel representing appellants and appellees, we entered our order on April 22, 1974, granting a short stay of the temporary injunction until the merits of the motion could be fully heard and decided upon full briefs and extended arguments by both sides. We scheduled a full hearing before the court on May 15, 1974, at the federal courthouse in St. Louis. We have now held that hearing and considered all material pertinent to the motion for stay, including Judge Lord's supplemental memorandum dated May 11, 1974, consisting of 109 typewritten pages of findings of fact and conclusions of law, expanding on his April 20th opinion. The question now before us is whether, considering all facts and circumstances, the injunction order should be stayed pending Reserve's appeal. We grant the stay subject to certain conditions and limitations as stated herein.

I.

A. *The Substance of the Controversy.*

Although there is no dispute that significant amounts of waste tailings are discharged into the water and dust is discharged into the air by Reserve, the parties vigorously contest the precise nature of the discharge, its biological effects, and, particularly with respect to the waters of Lake Superior, its ultimate destination. Plaintiffs contend that the mineral cummingtonite-grunerite,[4] which Reserve admits to be a major component of its taconite wastes and a member of the mineral family known as amphiboles, is substantially identical in morphology (or shape and form) and similar in chemistry to amosite asbestos, a fibrous mineral which has been found, in certain occupational settings, to be carcinogenic. The plaintiffs further argue that the mineral fibers discharged represent a serious health threat, since they are present in the air of Silver Bay and surrounding communities and, by way of dispersion throughout Lake Superior, in the drinking water of Duluth and other communities drawing water from the lake.

Reserve has maintained throughout this litigation that its cummingtonite-grunerite does not have a fibrous form and is otherwise distinguishable from amosite asbestos. Reserve further maintains the tailings cannot be said to pose any health hazard and, in any event, with respect to its discharge into water, the tailings largely settle to the bottom of the lake in the "great trough" area within close range of the plant.

The evidence presented on these points was extensive and complex. There was testimony as to the comparisons of mineralogy between Reserve's cummingtonite-grunerite and amosite asbestos, based on electron microscope analysis of morphology, x-ray diffraction analysis of crystal structure, and laboratory analysis of chemical composition. As for the dispersion through Lake Superior, there was considerable testimony as to whether Reserve was the sole source of cummingtonite-grunerite in the lake and whether the presence of the mineral could thus be used as a "tracer" for Reserve's discharge. The district court found, as plaintiffs contended, that Reserve discharged particles identical to and similar to amosite asbestos, and that the particles discharged into Lake Superior were dispersed widely.

The suggestion that particles of the cum-

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[1] *See Reserve Mining Company v. Minnesota Pollution Control Agency*, 200 N.W.2d 142 [2 ERC 1135] (Minn. 1972).

[2] Reserve's parent corporations, Armco Steel Corporation and Republic Steel Corporation, were joined as parties to the lawsuit after completion of the public health evidence, and have joined in the appeal. We shall make reference only to Reserve, the original defendant in the lawsuit.

[3] The stay request was made when judges of this court were attending a Joint Sentencing Institute with judges of the Tenth Circuit held at Springfield, Missouri. Chief Judge Mehaffy assigned Circuit Judges Bright, Ross, and Webster to the panel to hear the application. Recognizing that the matter was of considerable urgency, this panel arranged to hear counsel for the opposing parties on the motion as promptly as possible. This hearing, which was open to the public, was held at Springfield in a setting, made informal by necessity, on the evening of April 22, 1974.

[4] Cummingtonite-grunerite is a general name for a "suite" of minerals which are essentially identical except for the relative quantities of iron and magnesium in them. The iron-rich members are sometimes referred to as grunerites, although the word cummingtonite is used to refer to the entire suite of minerals.

mingtonite-grunerite in Reserve's discharges are the equivalent of amosite asbestos raised an immediate health issue, since inhalation of amosite asbestos at occupational levels of exposure is a demonstrated health hazard resulting in asbestosis and various forms of cancer. However, the proof of a health hazard requires more than the mere fact of discharge; the discharge of an agent hazardous in one circumstance must be linked to some present or future likelihood of disease under the prevailing circumstances. An extraordinary amount of testimony was received on these issues, and the district court designated several court witnesses to serve as impartial sources of review and evaluation.

B. *What the District Court Decided.*

The district court's conclusion—that Reserve's discharge into Lake Superior and its emissions into the air created a common law nuisance under federal and state law, and violated state and federal pollution laws—made the discharges subject to abatement. In determining the proper remedy, the court concededly balanced the equities and considered the economic and technological feasibility of abatement and the protection of the public health. The course of the proceedings indicate that the rather drastic remedy ordered by the district court—the immediate closing of the plant—was a response to the finding of a substantial danger to the public health. This is clear from the court's initial memorandum, where Judge Lord notes:

> The Court has no other alternative but to order an immediate halt to the discharge which threatens the lives of thousands. In that defendants have no plan to make the necessary modifications, there is no reason to delay any further the issuance of the injunction.

II.

We come now to our limited review of the district court's injunction ordering Reserve Mining to cease immediately its discharges into the air and water. In considering whether our temporary stay of that injunction should remain in effect, we note the usual formulation of the applicable standards to be met by the party seeking a stay under Fed. R. Civ. P. 62 and Fed. R. App. P. 8: (1) a strong showing that he is likely to succeed on the merits of the appeal; (2) a showing that, unless a stay is granted, he will suffer irreparable injury; (3) a showing that no substantial harm will come to other interested parties; and (4) a showing that a stay will do no harm to the public interest. *See, e.g., Long v. Robinson*, 432 F.2d 977, 979 (4th Cir. 1970).

The first element goes to the sensible administration of justice: a stay should not ordinarily be granted if the court determines that the injunction will ultimately take effect in any event. The other three elements, while distinguishable in some contexts, dissolve into a single equitable judgment: balancing the health and environmental demands of society at large against the economic well-being of those parties and local communities immediately affected. Of course, foremost consideration must be given to any demonstrable danger to the public health. *See United States v. Nutrition Service, Inc.*, 234 F.Supp. 578, 579 (W.D. Pa. 1964), *aff'd*, 347 F.2d 233 (3d Cir. 1965). Absent such demonstrated health danger, the public interest may arguably be served either way in environmental matters. In considering a stay application where no health hazard is shown, an appellate court must weigh, first, the seriousness of immediate harm to the environment which will result from allowing the alleged pollution to continue and, second, the economic and social dislocation to be suffered by the defendants and by the communities dependent upon them if the injunction immediately goes into effect. *See Friends of the Earth v. Armstrong*, 360 F.Supp. 165, 195 [5 ERC 1481] (D. Utah 1973); *Environmental Defense Fund, Inc. v. Froehlke*, 348 F.Supp. 338, 366 [4 ERC 1541] (W.D. Mo. 1972). Chief Justice Burger, sitting as circuit justice, while refusing to grant a stay in an environmental context in *Aberdeen & Rockfish R. Co. v. SCRAP*, 409 U.S. 1207 [4 ERC 1369] (1972), observed:

> Our society and its governmental instrumentalities, having been less than alert to the needs of our environment for generations, have now taken protective steps. These developments, however praiseworthy, should not lead courts to exercise equitable powers loosely or casually whenever a claim of "environmental damage" is asserted. The world must go on and new environmental legislation must be carefully meshed with more traditional patterns of federal regulation. The decisional process for judges is one of balancing and it is often a most difficult task. [409 U.S. at 1217-18.]

In relation to the motion for a stay, the parties have directed briefs and arguments almost exclusively to the health hazard issue. Given the concededly enormous economic impact that an immediate plant closure would have upon Reserve, given the personal impact on its approximately 3,000 employees and their families, and given the social and economic impact upon the communities in which the employees live, we think that our preliminary resolution of the health hazard question should control our action as to whether to grant or deny a stay.

III.
HEALTH ISSUE

A. *Testimony Before the District Court.*

The plaintiffs argue, and the district court found, that both Reserve's discharge into water and its discharge into air substantially endanger the health of residents in several communities around Lake Superior. We have reviewed the testimony on the health issue, giving careful and particular attention and weight, as we should at this interim stage of review, to the testimony of the impartial court witnesses and that of plaintiffs' chief medical witness, Dr. Irving Selikoff, Director of the Environmental Sciences Laboratory of Mt. Sinai School of Medicine. While not called upon at this stage to reach any final conclusion, our review suggests that this evidence does not support a finding of substantial danger and that, indeed, the testimony indicates that such a finding should not be made. In this regard, we conclude that Reserve appears likely to succeed on the merits of its appeal on the health issue. We proceed now to trace the outlines of the testimony supporting this view.

1. *Two Key Unknowns.*

The theory by which plaintiffs argue that the discharges present a substantial danger is founded largely upon epidemiological studies of asbestos workers occupationally exposed to and inhaling high levels of asbestos dust. A study by Dr. Selikoff of workers at a New Jersey asbestos manufacturing plant demonstrated that occupational exposure to amosite asbestos poses a hazard of increased incidence of asbestosis and various forms of cancer. Similar studies in other occupational contexts leave no doubt that asbestos, at sufficiently high dosages, is injurious to health.[5] However, in order to draw the conclusion that environmental exposure to Reserve's discharges presents a health threat in the instant case, it must be shown either that the circumstances of exposure are at least comparable to those in occupational settings, or, alternatively, that the occupational studies establish certain principles of asbestos-disease pathology which may be applied to predicting the occurrence of such disease in altered circumstances.

Initially, it must be observed that environmental exposure from Reserve's discharges into air and water is simply not comparable to that typical of occupational settings. The occupational studies involve direct exposure to and inhalation of asbestos dust in high concentrations and in confined spaces. This pattern of exposure cannot be equated with the discharge into the outside air of relatively low levels of asbestos fibers. While Dr. Taylor,[6] a court-appointed witness, testified that there are statistically significant higher levels of fibers in the air of Silver Bay than in the air of St. Paul, these levels still only amounted to .0626 [7] fibers per cubic centimeter of air, far below the five fibers per cc standard for permissible occupational exposure set by the Secretary of Labor under the Occupational Safety and Health Act. It is clear that the air of Silver Bay, though polluted by a statistically significant level of "excess" fibers, is not equivalent to the contaminated air found in an asbestos factory.

Nor can the occupational pattern of exposure be equated with the exposure resulting from the ingestion of fibers via the Duluth drinking water. This fact was confirmed by a tissue study, discussed in detail later in this opinion, in which the tissues of recently deceased Duluth residents were examined for asbestos fibers. The virtual absence of any fibers moved Dr. Brown, the principal court-appointed expert, to testify:

> Q. [Dr. Pooley stated in his summary of the tissue analysis that:] "There was no indication of an occupational exposure to asbestos dust."
>
> A. I agree with that.

Thus, it cannot be said that either the discharge into the water or the discharge into the air results in circumstances of exposure comparable to those in an occupational context.

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[5] *See Industrial Union Department, AFL-CIO, et al. v. Hodgson*, No. 72-1713 (D.C. Cir., filed April 15, 1974), slip op. at 6, n. 7, where the following appears as a quotation from the Secretary of Labor:

> No one has disputed that exposure to asbestos of high enough intensity and long enough duration is causally related to asbestosis and cancers. The dispute is as to the determination of a specific level below which exposure is safe.

[6] Dr. William F. Taylor is head of the Medical Research Statistics Section at the Mayo Clinic, and an expert in evaluating the significance of medical and biological statistics. He has been a consulting statistician in medical and biological research, and a Professor of Biostatistics.

[7] As noted subsequently in this opinion, such estimated counts are subject to a nine-fold margin of error. Thus, the actual count may be anywhere from 0.5634 fibers per cc to 0.0069 fibers per cc. The upper range of 0.5634 fibers per cc is, of course, still considerably below the standard set by the Secretary of Labor.

We do not make any comment here on the adequacy or relevancy of the standard, which was a matter in dispute before the district court. We cite the standard only as evidence that the level of exposure in the air of Silver Bay, even at its upper range, is far below the legally permissible level for occupational settings, and thus, obviously below those levels typically associated with occupational exposure.

The 5 fiber per cc standard was recently challenged and upheld. *See Industrial Union Department, AFL-CIO, et al. v. Hodgson*, No. 72-1713 (D.C. Cir., filed April 15, 1974), slip op. at 6, n.7.

If this is true, no conclusions about health hazards in occupational settings may be utilized in the present situation except on the ground that certain principles of asbestos-disease pathology may be extrapolated from relevant medical knowledge and applied in altered circumstances. The principal altered circumstance is the lower level of exposure. In order to make a prediction, based on the occupational studies, as to the likelihood of disease at lower levels of exposure, at least two key findings must be made. First, an attempt must be made to determine, with some precision, what that lower level of exposure is. Second, that lower level of exposure must be applied to the known pathology of asbestos-induced disease, *i.e.*, it must be determined whether the level of exposure is safe or unsafe.

Unfortunately, the testimony of Dr. Arnold Brown [8] indicates that neither of these key determinations can be made. Dr. Brown testified that, with respect to both air and water, the level of fibers is not readily susceptible of measurement. This results from the relatively imprecise state of counting techniques and the wide margins of error which necessarily result, and is reflected in the widely divergent sample counts received by the court. We cite some of the relevant testimony by Dr. Brown:

> [I]t is reasonable to assume an error in the counts of fibers in both water and air of at least nine times on the high side to one-ninth on the low side.
>
> * * *
>
> Well, in my thinking, Your Honor, as far as using the information that is supplied to the Court on counts, in view of the incredibly large errors associated with this procedure, I would have to assume virtually only a qualitative base for what is being reported. In other words, Your Honor, I do not recall having been exposed to a procedure with an error this large, and which people have seriously proposed a number based on this very poor procedure.
>
> * * *
>
> This [poor counting procedure] has somewhat wider implications, Your Honor, than just to the question of the presence of fibers in air and water.
>
> It has become, at least in my thinking, the kind of soft underbelly, if you will, of all of the research, much of the research, I should say, of the work that has been reported on asbestos in patients and in experimental animals.
>
> * * *
>
> Well, I interpret the information that was obtained in the water study as indicating that there are amphibole fibers, certainly, in the water of Lake Superior and in the water supply in Duluth. But I have little confidence in the estimate of the numbers. Which is another way of saying, Your Honor, that I consider the counts that I have been exposed to as qualitative, not quantitative in their implications. The same to be true in air.
>
> * * *
>
> Well, analytical tests are divided into two broad categories, one a qualitative test which is used merely to indicate the presence [or] absence of something. The quantitative kind of tests are used to quantify or measure with some degree of precision how much of that substance is present.

This testimony indicates that little more can be said about the level of fibers present in air or water other than that some fibers are present.

Even assuming that one could avoid imprecision and uncertainty in measuring the number of fibers at low levels, there remains vast uncertainty as to the medical consequences of low levels of exposure to asbestos fibers. In order to predict the likelihood and magnitude of disease resulting from exposure, one must have some idea of the relevant threshold value and dose-response relationships.[9] Although there seems to be agreement that threshold values and dose-response relationships are observable with respect to cancer generally, the particular values and relationships associated with asbestos-induced cancer appear to be unknown. Regarding this, Dr. Brown testified:

> Q. What is your view on the dose-response relationship between asbestos and cancer?
>
> A. I would like to approach that from the general point of view first. It is my view that in virtually—well, I will strike the word "virtually"—in every carcinogen that I know in which it has been possible to study whether or not a dose-response relationship exists, there has, indeed, been such a dose-response relationship. That is the general statement.
>
> Proceeding from the general to the specific, I would have to say that there is no reason for me to believe that asbestos [is] other than like any other agent, chemical, that causes cancer. So in a hypothetical way I would say that, yes, there is a dose-response relationship between asbestos and the development of cancer. I haven't the foggiest idea, Your Honor, as to what that level might be, either in air or in water.

In commenting on the statement, "This suggests that there are levels of asbestos exposure that will not be associated with any detectable risk," Dr. Brown stated:

> As a generalization, yes, I agree to that. But I must reiterate my view that I do not know what that level is.

2. *The Tissue Study.*

In the face of these two key unknowns in evaluating the risk of disease, we must now look to additional important evidence, a tissue study conducted at the request of the court and designed to measure the hazard to Duluth residents of ingesting fiber-contaminated water. This study was prompted by an almost complete lack of knowledge with respect to the human ingestion of asbestos fibers, since previous experiments had dealt largely with the effects of fiber inhalation, where interaction by asbestos with the respiratory tract was established. Any theory attempting to deal with the effects of ingestion of asbestos in liquid had to bridge the gap between the ingestion of fibers and the interaction by those fibers with the body tissues. If the fibers do not interact with the tissues but simply are eliminated by the body as wastes, presumably no disease will result. Accordingly, the court-appointed experts formulated a "protocol" or study plan designed to test whether people who drink Lake Superior waters accumulate asbestos-like fibers in body tissues from taconite.

This protocol involved analysis by electron microscope of the tissues of recently deceased Duluth residents who had ingested Duluth water for at least 15 years, that is, since the beginning of operations by Reserve. As a "control" check on results, samples were taken from the residents of Houston, Texas, where the water is free of asbestos fibers. Although this study was necessarily expedited, plaintiffs' principal medical witness, Dr. Selikoff, accepted its likely value:

> Q. And you regard that as a sound protocol which will provide significant information?
>
> A. I think so, sir.
>
> * * *
>
> * * * I think that their study has great value and we certainly would like to see the results of it.

Those results, as explained to the court by one of its own experts, Dr. Pooley,[10] indicated that the tissues of Duluth residents were virtually free of any fibers which could be attributed to the Reserve discharge.[11] Dr. Brown summarized the results as follows:

> It's my conclusion, from the tissue study, that residents of Duluth have not been found to have asbestiform fibers in their tissues when compared with Houston.

The significance which may be attributed to these results is a matter of dispute. Before the results were in, Dr. Selikoff had no hesitancy in forecasting that negative results would possess substantial significance, and stated:

> Now, our feeling was that no matter what air samples show or water samples show or anything else, unless it is found that asbestos is in the tissues of people who have drunk this water * * * if we do not find it in the tissues in appreciable quantities, then I would risk a professional opinion that there is no danger, at least up to this point, to the population no matter what our samples show or water samples.

Moreover, Dr. Brown, while suggesting that the tissue study did not exonerate Reserve's operations as a hazard, did state:

> It does tell me that it is not an emergency situation, and that's about as far as I can go.

Plaintiffs, however, sought subsequently to discount the significance of these tissue studies. First, the argument was made, and was accepted by the district court, that the specimens of tissue from body organs surveyed were too minute, and thus fibers that were present may have been overlooked. However, this judgment must be balanced by the following exchange between the court and Dr. Selikoff, which occurred prior to the conclusion of the study:

> THE COURT: And if we examine those

[8] Dr. Brown, a research pathologist associated with the Mayo Clinic of Rochester, Minnesota, served the court both in the capacity of a technical advisor and that of an impartial witness. As background for the expression of his opinions, he noted:

> I have been in attendance at many of the sessions that dealt with the public health issue personally, I have read the testimony of all those witnesses who testified in terms of the public health question as well as reading the testimony of those who I had heard in person, I have confined myself to the public health issue as I defined it before the Court or discerned it to be before the Court, and have paid no attention at all to any other matters before the Court in this case.

[9] A threshold value is that level of exposure below which no adverse health effects occur, while the dose-response relationship quantifies the association between disease-producing levels of exposure and the incidence of disease.

[10] Dr. Frederick D. Pooley is a world renowned scientist from Cardiff, Wales, Great Britain, and an expert in the field of identifying physical and chemical properties of asbestos and asbestos-like fibers. Dr. Selikoff, plaintiffs' expert, described Dr. Pooley as the "one man who has competence and knowledge in this matter," *i.e.*, the scientific examination of tissue for the presence of asbestos or asbestos-like fibers.

[11] Several aspects of Dr. Pooley's testimony regarding the tissue study should be noted. The few fibers which were found were not, in the main, "closely associated" with the tissue specimens, indicating that contamination was a likely source of the fibers. No "asbestos bodies," indicative of long-term residence of the fibers in the tissues, were found. Finally, there was no indication of occupational exposure characterized by very large numbers of fibers.

tissues and there are not fibers there, this operation is home-free as far as the health hazard goes?

THE WITNESS [Dr. Selikoff]: I would think we should find some fibers there. We're looking for needles in a haystack, but that's all right, we should find needles in the haystack with all the difficulties of the study, the technical difficulties, if we examine sufficiently large numbers of samples in some instances we should find some fibers there.

As noted previously, Dr. Selikoff had stated his belief that the design of the protocol was sound and would yield significant information. The weight to be given the tissue study has also been challenged on collateral grounds, most notably by testimony as to the increased rate of gastro-intestinal cancer among workers occupationally exposed to asbestos. This increased rate of gastro-intestinal cancer, it was theorized, is the result of asbestos workers' ingesting or swallowing particles during periods of exposure. However, a theory of ingestion is by no means the only basis for explaining the increased rates of gastro-intestinal cancer, and there is no scientific or medical certainty regarding the mechanism actually involved.

Although, based on our review of the testimony, we agree with Dr. Brown's statement that the ingestion of asbestos fibers cannot be exonerated as a hazard, we feel that, on any fair reading of the circumstances of the protocol, the results of the tissue study must weigh heavily against the assessment of any demonstrated hazard to health. We think it is clear that the tissue study raises a major obstacle to the proof that ingestion of Duluth water is hazardous. The study can only be overcome either by questioning the initial assessment, joined in by plaintiffs' chief medical witness, that the protocol was sound and would yield significant results, or by accepting the proposition that theoretical medical opinions alone may overcome direct evidence. Neither alone nor together can these two bases for attacking the study amount to affirmative evidence that ingestion of the water is harmful. At most, they only provide a theoretical but unsubstantiated basis for leaving the results of the study in doubt, and leaving the effects of ingestion unresolved.

B. *Evaluation of Testimony.*

A fair review of this impartial testimony by the court's own witnesses—to which we necessarily must give great weight at this interim stage of review—clearly suggests that the discharges by Reserve can be characterized only as presenting an unquantifiable risk, *i.e.*, a health risk which either may be negligible or may be significant, but with any significance as yet based on unknowns. This conclusion is simply a logical deduction from the following facts: (1) that fiber levels are not at occupational levels; (2) that the low levels present cannot be expressed or measured as a health risk; and (3) that, in any event, threshold values and dose-response relationships are undetermined. In other words, it is not known what the level of fiber exposure is, other than that it is relatively low, and it is not known what level of exposure is safe or unsafe. Finally, no basis exists, save a theoretical one, for assuming that drinking water, otherwise pure but containing asbestos-like particles, is dangerous to health.

We are confirmed in our evaluation by the testimony of Dr. Brown:

> I suspect I have stated my opinion on this before, and I don't recall now the precise words that I used, but I suspect I could sum it up by saying that in my review of the scientific literature that I would be unable to predict from that information that there will be an adverse effect that will occur in the citizens of Duluth or Silver Bay based on the presence of fibers in their environment.

Moreover, we believe there is essential agreement with this point by Dr. Selikoff, plaintiffs' chief medical witness. Although perhaps more expressive than Dr. Brown of the medical concerns which are posed by the unknown risks of Reserve's discharges, Dr. Selikoff seems to recognize that the likelihood of increased disease attributable to the discharges cannot be estimated:

> [W]e have no quantitative information on the relationship between the burden in tissues and the possible health effects.
>
> * * *
>
> Q. You don't have evidence that fibers, if they were ingested with the drinking water of Duluth would, in fact, occasion a public health hazard?
>
> A. No * * *

In the final analysis, Dr. Selikoff's vigorously expressed judgment that the discharges represent a danger reflects his underlying opinion that:

> I advocate that where, to the extent feasible, that carcinogenic substances should not be added to the environmental burden in which we live.

Dr. Brown expressed the same concern:

> [B]ecause asbestos is a known human carcinogen we have to know a lot more about it than we now know in order to establish safe limits for its presence. I have no expectations that our environment will ever be entirely free of asbestos. But until we know what safe limits are, as a physician, who would rather see well people than sick people, I have some sort of compulsion to protect ourselves against known agents that produce cancer until we know what the safe levels are. That is my entire base.

We think Doctors Brown and Selikoff share a common medical concern, but are essentially in agreement that the discharges here simply have not been proven to be a demonstrable hazard.

Interestingly enough, although Judge Lord does on occasion speak of a substantial health danger, based on the presence of asbestiform fibers in the environment, a careful reading of his initial and supplemental memoranda reveals an acknowledgement, at least in certain instances, that any ill effects are simply beyond proof. This is indicated in the "negative" findings which Judge Lord sometimes makes. For example, Judge Lord responds to the small number of excess deaths from rectal cancer in the Duluth area by finding:

> [W]e cannot say that the increase seen, although small in number at this time, is not due to ingestion by these persons of asbestos from Reserve's taconite waste.

Of course, neither can the opposite be said.[12] Perhaps the most revealing statement of all is contained in Judge Lord's initial memorandum:

> The state of the scientific and medical knowledge available in this area is in its early stages and there is insufficient knowledge upon which to base an opinion as to the magnitude of the risks associated with this exposure.

Considering all of the above, we think one conclusion is evident: although Reserve's discharges represent a possible medical danger, they have not in this case been proven to amount to a health hazard. The discharges may or may not result in detrimental health effects, but, for the present, that is simply unknown. The relevant legal question is thus, what manner of judicial cognizance may be taken of the unknown.

We do not think that a bare risk of the unknown can amount to proof in this case. Plaintiffs have failed to prove that a demonstrable health hazard exists. This failure, we hasten to add, is not reflective of any weakness which it is within their power to cure, but rather, given the current state of medical and scientific knowledge, plaintiffs' case is based only on medical hypothesis and is simply beyond proof.

We believe that Judge Lord carried his analysis one step beyond the evidence. Since testimony clearly established that an assessment of the risk was made impossible by the absence of medical knowledge, Judge Lord apparently took the position that all uncertainties should be resolved in favor of health safety. Since the appropriate threshold level for safe toleration of fibers was unknown, the district court tipped the balance in favor of attempting to protect against the unknown and simply assumed that Reserve's discharge presents a health hazard. In doing so, he disregarded the tissue studies of his own experts which provided direct evidence to the contrary. If we are correct in our conclusion that evidence does not exist in the record on which to find Reserve's discharges to be unsafe, the district court's determination to resolve all doubts in favor of health safety represents a legislative policy judgment, not a judicial one. *See Industrial Union Department, AFL-CIO, et al. v. Hodgson*, No. 72-1713 (D.C. Cir., filed April 15, 1974), slip op. at 13. As Judge McGowan stated in *Industrial Union Department, AFL-CIO*, with regard to legislative resolution of a similar issue:

> [S]ome of the questions involved in the promulgation of these standards are on the frontiers of scientific knowledge, and consequently as to them insufficient data is presently available to make a fully informed factual determination. Decision making must in that circumstance depend to a greater extent upon policy judgments and less upon purely factual analysis. [*Id.* at 13.]

We emphasize that our evaluation rests not on any view that the discharge exposes North

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[12] Dr. Brown came to the following conclusions from the epidemiological studies of cancer relating to North Shore communities:

> Q. Well, let me ask you this directly, Dr. Brown. Do you believe that there is any significant evidence, on an epidemiological basis, to reflect that there is any excess of cancer in Duluth that could be attributed to the ingestion of any fibers in Lake Superior water?
>
> A. [Dr. Brown] No, there is no evidence.
>
> Q. Similarly, do you believe that there is any epidemiological evidence of residents, in Two Harbors, Silver Bay, Beaver Bay or elsewhere on the North Shore, that would indicate any excess of cancer which could be attributed to the ingestion of Lake Superior water?
>
> A. There's no such evidence that I've been exposed to. And I've looked rather hard for it.
>
> Q. Similarly, is there any epidemiologic evidence, in your judgment, that would indicate any excess of cancer in the residents of Silver Bay or Babbitt, which could be attributed to the inhalation of air-borne fibers?
>
> * * *
>
> THE WITNESS: Scientifically and medically I see no evidence for an increased incidence of cancer in those communities that could be attributed to the presence of asbestos fibers in air or water.

These statistics must be taken as inconclusive, however, since, even as to workers occupationally exposed to asbestos, there is a time lag of 20 or more years between the date of the initial exposure and the onset of cancer in those so exposed.

Shore residents to no risk, but rather on the view that, given the evidence, no substantial danger has been, or could be proven. It cannot be said, other than as a matter of conjecture, that the discharges will result in any higher incidence of disease than that experienced by a general public not similarly exposed. Although we are sympathetic to the uncertainties facing the residents of the North Shore, we are a court of law, governed by rules of proof, and unknowns may not be substituted for proof of a demonstrable hazard to the public health.

IV.

After our examination of the relevant portions of the lengthy record in this case, we come to these conclusions: (1) it is unlikely that Reserve will prevail on the merits of the pollution issue and overcome the trial court's determination that pollution of Lake Superior must be abated; (2) it is also unlikely that Reserve will overcome the trial court's determination that the air emission must be controlled; but (3) Reserve, as we have demonstrated, may well prevail in its contention that its emissions into the air and water have not proven to be a substantial health hazard. If and when our court is called upon, on the appeal on the merits, to affirm or modify the terms of the injunction based upon the existence or nonexistence of a substantial health hazard, we can forecast, on the showing presently made, that Reserve will succeed on the health hazard issue. However, the district court's findings on the pollution aspects of this case appear to be based on sufficient evidence, apart from mere speculation, to withstand our initial scrutiny. Therefore, in the posture of this motion, we cannot forecast any success for Reserve in upsetting these findings relating to pollution, and are satisfied that the circumstances call for a stay conditioned upon assurances that there will be a speedy termination of Reserve's discharges into Lake Superior and control of its emission into the air.

The controversy between Reserve and governmental agencies over alleged pollution of Lake Superior has existed for more than five years. In retrospect, it must now be painfully clear to all who participated in the original decision to permit the discharge of tailings into Lake Superior, that such a decision amounted to a monumental environmental mistake. The actors in that decision, 25 years ago, included leading citizens and governmental officials of Minnesota as well as officials of Reserve, Armco, and Republic Steel. That decision obviously was made in good faith to create jobs, to provide other economic opportunities in an economically depressed area of northern Minnesota, and to utilize the almost unlimited supply of hitherto unusable, low-grade, taconite ore found in that area. To us there are neither heroes nor villains among the present participants in this lawsuit, nor among their predecessors in government, business, and society who were once allies in encouraging and creating a taconite industry in northern Minnesota. Nevertheless, the pollution of Lake Superior must cease as quickly as feasible under the circumstances.

Accordingly, our stay of the injunction will be conditioned upon Reserve taking prompt steps to abate its discharges into air and water. We invited Reserve to advise this court concerning plans for the on-land disposal of its tailings and the significant control of its air emissions. Reserve's counsel stated that the company envisioned a three and one-half year to five year "turn-around" time, but added that investigation continues in an effort to reduce further the time for achieving abatement.

Our stay of the injunction rests upon the good faith preparation and implementation of an acceptable plan.[13] Therefore, we grant a 70-day stay upon these conditions:

1) Reserve's plans shall be promptly submitted to plaintiff-states and to the United States for review and recommendations by appropriate agencies concerned with environmental and health protection. Such plan shall be filed with the district court and submitted to all plaintiffs in no event later than 25 days from the filing of this order.

2) Plaintiffs shall then have an additional 20 days within which to file their comments on such plan.

3) The district court shall consider Reserve's plan and any recommendations made by the United States and plaintiff-states and make a recommendation, within 15 days following submission of plaintiffs' comments, whether or not a stay of the injunction should be continued pending the appeal.[14]

4) Based on these plans, comments, and recommendations, this court will then review the status of its stay order within the time remaining.

We remand this aspect of the case to the district court for its recommendation, such recommendation and record to be delivered to us no later than 60 days from the filing of this order.

We add a comment. At oral argument counsel for all parties indicated that the controversy ought now to be settled. Counsel for Reserve suggested a Master or Referee ought to be appointed who could "in some way establish some mechanism that could focus on whether or not there is a reasonable basis for resolution of this controversy." Counsel for the United States indicated amenability to settlement, stating "I think this case ultimately has got to be settled." Counsel for the State of Minnesota at argument advised the court that Judge Lord during trial contemplated keeping Reserve in operation conditioned upon future settlement.

We think settlement of this kind of case represents a necessary and desirable goal, and the matter should be pursued in the district court. One possible approach is the use of mediation techniques in resolving disputes on technical matters by utilizing experts from business and science who can assist the parties in reaching a settlement or can advise the district court on technical matters in his consideration of Reserve's plan. Judge Lord has demonstrated innovative techniques in trying this case by bringing into court some of the world's leading scientists, physicians, and other experts in seeking resolution of the controversy before him. Although we do not find ourselves, at least at this point in the lawsuit, in full agreement with Judge Lord's views on the health issue, this disagreement in no way detracts from our confidence in his ability to assist the parties to achieve a meaningful and appropriate settlement.

Finally, we emphasize that our stay is also conditioned upon prompt presentation of the merits of this appeal. The court authorizes the preparation of a deferred appendix pursuant to Fed. R. App. P. 30(c), and consents to briefs not to exceed 100 pages, subject to the further order of this court. The briefing schedule may be expedited at the request of Reserve or of any of the government parties.[15]

SUMMARY

We summarize:

1) On appeal, Reserve is likely to prevail on the merits of whether the evidence supports the district court's finding that Reserve's emissions into the air and its discharges into the water substantially endanger the public health.

2) The plaintiffs (state and federal governments and environmental groups) are likely to prevail on the merits of whether the evidence establishes that Reserve's present operations otherwise pollute the air and water.

3) It is likely that abatement will ultimately be required upon reasonable terms that take into consideration the multiple environmental, social, and economic interests involved.

4) We grant a stay of injunction for 70 days upon conditions stated in item 5 herein, and as amplified in the opinion.

5) This stay is conditioned upon a showing by Reserve that it is taking prompt steps to prepare and implement an appropriate plan for abatement, which it has represented to the court that it is now ready to do.

6) We remand this case to the district court for the purpose of receiving its recommendation for continuance of the stay order, after it has considered Reserve's plan and plaintiffs' comments on that plan, and for the further purpose of assisting the parties in attempting to reach agreeable settlement of the controversy, such settlement to be consistent with the public interest.

IT IS SO ORDERED.

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[13] We note that the trial court has characterized Reserve's approach to abatement as one of "intransigence" and seems to have considered this as a factor in closing down the plant. *See* Judge Lord's Memorandum of April 20, 1974, at 12. In his supplementary memorandum, Judge Lord commented critically on Reserve's failure in this litigation to present the trial court with a reasonable proposal for on-land disposal of its taconite tailings and control of its air emissions and noted that Reserve continued to produce unrealistic proposals despite his admonition last February that the Government had made a prima facie case. The crucial court-designated medical and scientific witnesses were yet to be heard; the results of tissue studies were yet to be fully evaluated and explained. Counsel for the State of Minnesota on oral argument, in response to questions from the bench about Reserve's defense on the health issue, stated, "there's no bad faith" in the record with respect to the health hazard." We expect that the parties will cooperate in achieving a plan acceptable to all concerned.

[14] The recommendation should rest on whether Reserve and its parent companies have evidenced good faith efforts and a reasonable plan in the public's interest to abate the pollution of air and water, taking into account the views expressed in this opinion.

[15] The district court should enter its final judgment in the action as promptly as possible or explain what matters should remain open pending final resolution of Reserve's pending appeal seeking reversal of the injunction.

U.S. DISTRICT COURT JUDGE MILES LORD'S RULING IN THE CASE OF U.S. vs. RESERVE MINING COMPANY:

MEMORANDUM AND ORDER

This action for injunctive relief is before the Court after 139 days of trial, which included testimony from well over 100 witnesses, over 1621 exhibits, and over 18,000 pages of transcript. Of necessity, it will require several weeks before the Court will be able to set forth in writing its detailed findings of fact and conclusions of law. Inasmuch as the case deals with issues concerning public health, the ultimate resolution of the problem should not be delayed by this procedural matter. The Court has carefully considered all of the evidence and hereto sets forth its essential findings of fact and conclusions of law to be refined and supplemented at a later date.

Findings of Fact

1. Reserve Mining Company (Reserve) is set up and run for the sole benefit of its owners, Armco Steel Corporation (Armco) and Republic Steel Corporation (Republic), and acts as a mere instrumentality or agent of its parent corporations. Reserve is run in such a manner as to pass all its profits to the parents.

2. Reserve acting as an instrumentality and agent for Armco and Republic discharges large amounts of minute amphibole fibers into Lake Superior and into the air of Silver Bay daily.

3. The particles when deposited into the water are dispersed throughout Lake Superior and into Wisconsin and Michigan.

4. The currents in the lake, which are largely influenced by the discharge, carry many of the fibers in a southwesterly direction toward Duluth and are found in substantial quantities in the Duluth drinking water.

5. Many of these fibers are morphologically and chemically identical to amosite asbestos and an even larger number are similar to amosite asbestos.

6. Exposure to these fibers can produce asbestosis, mesothelioma, and cancer of the lung, gastrointestinal tract and larynx.

7. Most of the studies dealing with this problem are concerned with the inhalation of fibers; however, the available evidence indicates that the fibers pose a risk when ingested as well as when inhaled.

8. The fibers emitted by the defendant into Lake Superior have the potential for causing great harm to the health of those exposed to them.

9. The discharge into the air substantially endangers the health of the people of Silver Bay and surrounding communities as far away as the eastern shore of Wisconsin.

10. The discharge into the water substantially endangers the health of the people who procure their drinking water from the western arm of Lake Superior including the communities of Beaver Bay, Two Harbors, Cloquet, Duluth and Superior, Wisconsin.

11. The present and future industrial standard for a safe level of asbestos fibers in the air is based on the experience related to asbestosis and not to cancer. In addition its formulation was influenced by more technological limitations than health considerations.

12. The exposure of a non-worker populace cannot be equated with industrial exposure if for no other reason than the environmental exposure, as contrasted to a working exposure, is for every hour of every day.

13. While there is a dose-response relationship associated with the adverse effects of asbestos exposure and may be therefore a threshold exposure value below which no increase in cancer would be found, this exposure threshold is not now known.

Conclusions of Law

1. The Court has jurisdiction over the subject matter of the various claims pursuant to 28 U.S.C. §§ 1345 and 1331. As to those claims based upon state law, the Court exercises its jurisdiction pursuant to the doctrine of pendant jurisdiction.

2. Reserve's discharge into the water is in violation of the Federal Water Pollution Control Act as amended in 1970, 33 U.S.C. § 1151 et seq. The violations involve both interstate and intrastate waters and are subject to abatement pursuant to 33 U.S.C. §§ 1160(c) (5) and (g) (1). Specifically Reserve's discharge is in violation of water quality standards referred to as WPC 15 (A) (4), (c) (6) and (c) (2).

3. Reserve's discharge into the water creates a common law nuisance in both interstate and intrastate waters of Lake Superior.

4. Reserve has no permit that sanctions its violations of the Federal Water Pollution Control Act as amended in 1970.

5. Reserve has no permit that sanctions its creation of a common law nuisance in the waters of Lake Superior.

6. Reserve's discharge into the air creates a common law nuisance condition in the ambient air in Silver Bay and the surrounding communities and is subject to abatement. Furthermore, the air discharge violates Minnesota Regulations APC 5,6 and 17.

7. Industrial standards for asbestos exposure do not apply to environmental exposure and are therefore not applicable to the fact in this case.

8. In that Reserve is a mere instrumentality or agent of its parents who have used Reserve as a shield to protect themselves from the consequences of Reserve's illegal pollution of Lake Superior, Armco and Republic must bear legal responsibility for Reserve's actions. Furthermore, since Reserve's profits are siphoned off by its parents, in order to insure an effective remedy if civil fines or other monetary relief are called for, the independent corporate entity of Reserve must be disregarded.

9. All additional legal questions including the question of civil fines, financial responsibility for water filtration systems in Lake Shore communities alleged violations of the Refuse Act, 33 U.S.C. §§ 407, specific Wisconsin criminal and civil statutes as well as the Wisconsin Public Trust Doctrine, and Reserve's counterclaims against the State of Minnesota are taken under advisement and will be decided at a later date. The question as to what part of the potential fines and penalties should be awarded to Reserve employees or others who would lose their jobs is likewise held for further argument and consideration.

Memorandum

It has been clearly established in this case that Reserve's discharge creates a serious health hazard to the people exposed to it. The exact scope of this potential health hazard is impossible to accurately quantify at this time. Significant increase in diseases associated with asbestos exposure do not develop until 15 to 20 years after the initial exposure to the fibers. The state of the scientific and medical knowledge available in this area is in its early stages and there is insufficient knowledge upon which to base an opinion as to the magnitude of the risks associated with this exposure. . . .

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ghost town soon?

SILVER BAY, Minn. (AP) Two northeastern nnesota communities today ced the prospect of oming little more than e welfare towns with their n employer, the Reserve ng Co., shut down.
ver Bay and any to...

earn $34 million a year are ou of work in the two towns whose combined popula... 6,500. Officials of... said virtu... perso...

endangering the h... communities in Minneso... and Wisconsin which draw their drinking water from the lake.

In all, 3,100 persons w...

court rejected. The order ... announcing the ruling noted Justice William O. Douglas favored granting Minnesota's request..

Court Closes Lake Po...

Judge Orders Halt to Waste Dumping in Lal...

The dumping of iron ore wastes into Lake Superi... was halted briefly last month by a Federal Dis... court judge, but then resumed pending an appe... scheduled to start May 15.

POLLUTION

The Classic Case

immediate health ...

The basic issues could not be simpler —even though they have taken 8½ months, more than 800 official exhibits and 18,500 pages of court testimony to spell out. Indeed, the federal court suit against Reserve Mining Co. has become the classic pollution case because it poses so sharply the questions of whether or not damage to a region's environment is worse than damage to the same region's economy, and of who should pay for cleaning up pollution. Ten plaintiffs, including the Federal Government and the states of Michigan, Wisconsin and Minnesota, want a Reserve plant to stop discharging what they regard as harmful emissions into the air and Lake Superior. In reply, Reserve says that the emissions pose no danger to public health, that to stop them it would have to close down, and that if the governments are so anxious for a cleanup, they should pay for it.

Back to Court. Two weeks ago, the case seemed resolved, but the solution was short-lived. Federal District Court Judge Miles Lord, who has a reputation for being tough but fair, abruptly ordered the company to stop its discharges —period. But last week Reserve's lawyers, arguing that the action would cause "irreparable damage" to the company and the local economy, won a stay of that order. Result: what is already the longest environmental trial in U.S. history will go back to the courts.

Reserve Mining, which is owned jointly by Armco Steel and Republic Steel, produces 15% of the U.S.'s iron ore. It mines taconite around Babbitt, Minn., then ships the flintlike rock 50 miles to Silver Bay, on the shores of Lake Superior. There the iron content of the taconite is extracted, and the wastes, or "tailings," are dumped into the water. Any time that Reserve is attacked for polluting the lake—and the attacks have been continuous since 1967—it says that it might have to close the plant if ordered to stop. That would wreak economic havoc, since the company employs 3,100 workers in the area, or at least 90% of the local work force. But in February 1972, the U.S. Justice Department decided to sue for a cleanup anyway. The trial began last summer.

The key issue became public health. Asbestos fibers had been discovered in the drinking water that five communities, including Duluth, 60 miles down the shoreline, draw from Lake Superior. Federal scientists pinpoint Reserve's taconite tailings as the source of the asbestos. Company experts say that the material leaches naturally out of surrounding rock formations. Either way, the minute fibers are dangerous. If ingested or inhaled—and particles have been detected in the air over Reserve's Silver Bay plant—asbestos can cause cancer.

The ideal solution would be for Reserve Mining to dispose of its wastes on land. But company officials testified that Reserve had no plan for land disposal, and would need time to prepare one. The executives also rejected a Government proposal that Reserve move its entire Silver Bay operation to Babbitt. Such a move would cost $187 million, said federal officials. Reserve promptly upped the estimate to $575 million, a figure that Judge Lord scrutinized and then branded as "blatantly inflated." On March 1, an Armco executive admitted that Reserve Mining had in fact prepared four or five on-land disposal plans. The judge was aghast. He charged the company ...

...100 employees of t... with deliberately stalling the trial in the ... of two Min... hope of getting the Government to step ... in and pay for the cleanup.

Political Influence. Two weeks ago, ... the trial hit its emotional peak when Minnesota Deputy Attorney General ... Byron Starns read notes that supposedly ... were made during a Reserve board meeting in 1971. The notes, purportedly ... written by Armco Steel Vice President ... Harry Holiday Jr., indicated that Reserve and its parent companies had tried ... to use their political influence in Minnesota and Washington to keep the case ... out of court. Judge Lord was shocked. "If ... what is represented in this document is taking place every day in the lives of the corporations of our country," he said, "then I fear for our country."

Lord left no doubt that his decision would be based on Reserve Mining's willingness to clean up its operations. On the trial's final day, Reserve Chairman C. William Verity said that the company would build a $172 million on-land disposal system—provided it got federal financial assistance. Lord called his proposal "absurd." He ordered "an immediate curtailment of the discharges." In order to comply, the company really did briefly shut down its Silver Bay plant.

The court's decision dismayed Reserve's employees and their families but was widely praised elsewhere. Reserve Mining lost no time in obtaining a stay from an emergency panel of three circuit court judges who convened at night around a dining table in a restaurant in Springfield, Mo. Later this month the full appellate court will hear the company's appeal for a permanent stay. Meantime, the employees are back at work, and every day the big plant at Silver Bay is spilling 67,000 tons of taconite tailings into Lake Superior.

...ay be enab... ...year or two

By JAMES L. KERWIN
News Staff Writer

...ears that a Minnesota firm will be permitted to dump mining ...wastes into Lake Superior for another five years are ...exaggerated, according to federal officials following a court ...battle over the dumping.

...observers say Reserve Mining Co. probably will be ...n years at the most — to switch to on-land ...ting the lake.

...Minnesota ordered Reserve ...

5 More Years

New York Times Service

ST. LOUIS — A three-judge federal appeals court pan... handed down an opinion Tuesday that apparently will allo... the Reserve Mining Co. to continue to pollute Lake Superio... for up to five more years.

The panel found too little evide... trict judge's finding th...